ANNUAL GENERAL MEETING.
30th MARCH, 1960.

The Eighty-fifth Annual General Meeting was held in the Society's Rooms, Science House, 157 Gloucester Street, Sydney, on Wednesday, 30th March, 1960.

Dr. T. G. Vallance, President, occupied the chair.

The minutes of the Eighty-fourth Annual General Meeting, 25th March, 1959, were read and confirmed.

PRESIDENTIAL ADDRESS.

Before I proceed to bore you with technical jargon there are some important Society matters to which I wish to refer. First of all I want to express my own very warm thanks and I am sure those of all members to our two honorary officers, Dr. A. B. Walkom and Dr. W. R. Browne. These gentlemen have continued to do yeoman service on behalf of the Society and their efforts must not be left unregarded. I should also like at this time to put on record our thanks to our Assistant Secretary, Miss G. Allpress, for her faithful service during the past year.

The Society's PROCEEDINGS for 1959, Volume 84, Parts 1 and 2, were published in 1959 and Part 3 in February, 1960. Volume 84 consists of 432 pages, 23 plates and 287 text-figures. Payment for a two-colour plate to illustrate a paper by E. Gauba and L. D. Pryor entitled "Seed Coat Anatomy and Taxonomy in *Eucalyptus*. II" was made by the Department of the Interior, Canberra. An increase of 10% on charges for printing the PROCEEDINGS was made commencing with Volume 84, Part 2.

During the year nine new members were added to the list, two members died, and nine members resigned. The numerical strength of the Society at 1st March, 1960, was: Ordinary Members, 224; Life Members, 32; Corresponding Members, 2; total, 258.

On 20th May, 1959, Professor B. J. F. Ralph was elected a member of Council in place of Dr. Dorothy A. Thorp.

Lecturettes were given at the following meetings: April, Wild Life of Macquarie Island, by Mr. Durno Murray; June, Fossil Spores and Pollen Grains, by Mr. J. P. F. Hennelly; September, Vegetation of South-East England, by R. F. Cosser; October, Some Problems of New Guinea Zoogeography, by Dr. D. F. McMichael. A symposium on "Laterite" was held at the July meeting, the principal speakers being Dr. W. R. Browne, Mr. P. H. Walker and Professor F. V. Mercer (deputizing for Professor R. L. Crocker). We wish to thank all lecturers and express our appreciation to them and to all members who brought notes and exhibits to meetings, thus ensuring interesting contributions and discussions. Small attendances at Ordinary Monthly Meetings are still causing concern to the Council.

Library accessions from scientific institutions and societies on the exchange list amounted to 2,076 compared with 1,727 in the previous year. Requests for library loans from members and institutions continued to be made as frequently as previously. A small number of volumes in the library was bound. The PROCEEDINGS were offered to the Beaudette Foundation, Solvang, California, in exchange for "Pacific Naturalist"; Tokyo Agricultural University, Tokyo; and Escuela de Biologia, Facultad de Ciencias, Universidad Central de Venezuela, Caracas, Venezuela, for "Acta Biologica Venezuela". Geological Reprints were offered to Geological Institute, Kumamoto University, Kumamoto, Japan. Exchange relations with Faculté des Sciences, Université d'Aix-Marseille, Marseille, France, were discontinued. "Physis", Buenos Aires, Argentina, is now obtained by subscription. Advantage was taken of an opportunity to purchase three volumes and three General Indexes to complete our set of "Journal de Conchyliologie".

PROCEEDINGS OF THE LINNEAN SOCIETY OF NEW SOUTH WALES, 1960, Vol. lxxxv, Part 1.

A

The total net return from the Society's one-third ownership of Science House for the year was £1,447 15s. 6d. Owing to the Royal Society of New South Wales relinquishing its tenancy of the Reception Room on the ground floor of Science House as from 31st May, 1959, the Joint Management Committee decided that in future the room should be known as the Edgeworth David Room and be used as a Conference, Committee and Reception Room.

Under the auspices of the Royal Society of New South Wales and the Linnean Society a meeting was held on 3rd June, 1959, to celebrate the centenary of the publication of Darwin's "Origin of Species". The commemorative address entitled "Charles Darwin" was delivered by Professor P. D. F. Murray.

On 5th August, 1959, the Stuart Drawings and some old maps, etc., were handed to the Mitchell Library, Sydney, on the following conditions, which were accepted by the Trustees of the Mitchell Library: (1) That they remain the property of the Society, and be accepted by the Library on permanent loan; (2) that they be suitably housed and cared for; (3) that in any exhibition of them or any reproductions of them made or published, the fact of their being the property of this Society be clearly stated; (4) that facilities for access to them be guaranteed to members of this Society; and (5) that insurance against their loss or damage be effected.

On 29th September, 1959, three swords in the Society's possession for many years were handed to the Museum of Applied Arts and Sciences, Broadway, Sydney, on permanent loan.

Mr. R. H. Anderson was asked to represent the Society at the Third Annual Conference of Nature Conservation Bodies (N.S.W.) held on 8th August, 1959. Professor B. J. Ralph was appointed the Society's representative to the Centenary Symposium (December 7–11, 1959) of the Royal Society of Victoria. Dr. Gordon H. Packham was asked to act as delegate for the Society at the International Geological Congress, XXI Session, Copenhagen, 1960.

During the year an unsuccessful request was made to the Prime Minister for a Commonwealth contribution towards the maintenance of the scientific libraries of the Royal Societies in each State and/or the Linnean Society of New South Wales.

On account of increased postage charges from 1st October, 1959, the postage on the complete volume of the Society's PROCEEDINGS was raised to four shillings.

I should like to take this opportunity to announce that the Second Sir William Macleay Memorial Lecture will be delivered by Professor Theodosius Dobzhansky, Columbia University, New York, on Wednesday, 29th June, 1960, at 8 p.m., in the Main Hall, Science House, Sydney.

Linnean Macleay Fellowships.

Miss Alison McCusker, M.Sc., who was appointed to a Fellowship in Botany for 1959 in November, 1958, studied pollen development in some species of the Styphelieae. In the early part of the year a project of work on local populations of *Astroloma pinifolium*, begun previously, was concluded, and a paper written in conjunction with Dr. S. Smith-White was accepted for publication in the PROCEEDINGS. Material of the same species was collected from Victoria, and a preliminary investigation of its cytological conditions was made. An investigation of the genetic system of *Leucopogon melaleucoides* was undertaken during the second quarter, and as this proved to be especially profitable, the remainder of the year was devoted to it. Extensive studies of meiosis in microspore mother cells were made, and data concerning megaspore development and pollen and seed production were collected from two localities. From June to October these studies were carried out at the laboratories of the University of New England by courtesy of Professor N. C. W. Beadle.

No appointment was made for 1960.

Your Council had for some time been concerned at the fact that the salary offered for a Linnean Macleay Fellowship suffered in comparison with salaries for fellowships

and scholarships of somewhat equal standing. It therefore decided to petition the Equity Court for power to offer a salary not exceeding £1,600 per annum for a fellowship. On 17th December, 1959, the petition came before the Court and His Honour Mr. Justice Myers made the following order: (1) The salary of a Fellow shall be an amount not less than £400 and not more than £1,600 per annum as the Council of the Society shall decide; (2) the Council of the Society may, upon the application of a Fellow, make grants to him out of the remaining income from the Linnean Macleay Fellowship Fund received by the Society in any year provided the total sum including the salary or salaries paid to the Fellow or Fellows during such year does not exceed £1,600, to defray field and other research expenses incurred or to be incurred in carrying on work and investigations as such Fellow or Fellows; and (3) that the cost of all parties are to be paid out of the Fund.

Opinion was obtained from the Society's solicitors that Fellows were not employees in terms of the Workers' Compensation Act or the Income Tax Act. Fellows were to be informed that they were not covered by insurance under the Workers' Compensation Act.

Linnean Macleay Lectureship in Microbiology.

The following is a brief report on the work of Dr. Y. T. Tchan, Linnean Macleay Lecturer in Microbiology, University of Sydney, for the year ended 31st December, 1959: Due to the absence of the Head of the Microbiology Section (Associate Professor J. M. Vincent) he has been heavily loaded with teaching and administration work. However, some research work has been done on the soil algal method. A paper is under preparation for publication. The results of this work indicate that algal techniques could, under certain circumstances, replace the pot trial with higher plants.

Obituaries.

It is recorded with regret that the following members died during the year:

Mr. Anthony Musgrave, F.R.E.S., F.R.Z.S., who was Curator of Insects and Arachnids at the Australian Museum, Sydney, and had been a member of the Society since 1920, died suddenly in Sydney on 4th June, 1959, at the age of 64. Mr. Musgrave was born at Cooktown, Queensland, on 9th July, 1895, his father, Captain the Hon. Anthony Musgrave, C.M.G., being Deputy Commissioner, and later Government Secretary of British New Guinea. He joined the staff of the Museum as a cadet on 7th February, 1910, and, after a year in the library, was appointed assistant to the then entomologist, Mr. W. J. Rainbow. In 1920, after Mr. Rainbow's death, Mr. Musgrave was appointed entomologist, a title later altered to Curator of Insects and Arachnids. He joined the Royal Zoological Society of New South Wales in 1919 or 1920, was a member of its Council from 1920 to 1935, and was elected President in 1929–30 and a Fellow in 1933. He was also a Fellow of the Royal Entomological Society of London, and a member of the Royal Australian Historical Society, serving on the Council of that Society in 1956 and 1957. He was interested in the vast literature on Australasian and Pacific entomology and his bibliographical work was amazingly detailed. His monumental "Bibliography of Australian Entomology, 1775–1930, with Biographical Notes on Authors and Collectors" was published by the Royal Zoological Society of New South Wales in 1932 and was kept up to date by him on cards. He also compiled, for about twenty years, all the zoological entries for "Australian Science Abstracts" until they ceased publication in 1957. A bibliography of his writings is in course of preparation for publication. An obituary notice (with portrait) appears in the *Australian Museum Magazine*, Vol. XIII, No. 3 (September 15, 1959). Mr. Musgrave used the Society's library extensively and was a frequent attendant at monthly meetings, taking an active part in their programmes.

Mrs. Nance (Anne) Zeck, wife of Mr. E. H. Zeck, died in Sydney on 3rd November, 1959. Mrs. Zeck had been a member of the Society since 1949.

PRESIDENTIAL ADDRESS.

Concerning Spilites.

The term spilite was introduced by Brongniart probably before 1819. Originally, rocks of rather diverse character were grouped under this name but today spilite is used most often in the restricted sense of Dewey and Flett (1911), that is, for fine-grained or even partly glassy basic rocks in which the typical feldspar is albite. Spilites in which K-feldspar occurs as well as albite are also recognized. However, not all petrographers regard the presence of alkali feldspars as essential.

Spilites occur most frequently as submarine lavas or shallow intrusive bodies in eugeosynclinal environments. They have also been found in epicontinental and continental associations and in some of these cases may have been subaerial. There are even records of intrusive spilites apparently unrelated to effusive vulcanism. Geosynclinal spilites occur with ultrabasic bodies or with keratophyres and other more acid rocks. Ultrabasic rocks are typically subordinate or lacking in the epicontinental and continental associations.

Spilites, even within, say, a single flow, are variable in fabric, mineralogy and composition. Calculated "average spilites" are suspect because of probable bias in sampling. The bulk composition of spilite bodies may not be much different from the composition of normal basalts, only water and, sometimes, carbon dioxide being more abundant in spilites. Mineral assemblages of the type found in spilites can form in a variety of ways, by magmatic action, hydrothermal alteration, low-grade metamorphism, or diagenesis. In some spilites there is clear evidence of replacement of primary magmatic phases but in others where such evidence is lacking the present phases may themselves be primary, having separated from exceptionally hydrous magmas. There is no unique explanation to account for the genesis of all rocks called spilites. I prefer to regard most of them as essentially basaltic rocks which have become adjusted, either magmatically or post-magmatically, to a low-temperature hydrous environment. (For full text see pp. 8 *et seq.*)

The Honorary Treasurer, Dr. A. B. Walkom, presented the balance sheets for the year ended 29th February, 1960, duly signed by the Auditor, Mr. S. J. Rayment, F.C.A., and his motion that they be received and adopted was carried unanimously.

No nominations of other candidates having been received, the Chairman declared the following elections for the ensuing year to be duly made:

President: I. V. Newman, M.Sc., Ph.D.

Members of Council: W. R. Browne, D.Sc.; R. L. Crocker, D.Sc.; I. V. Newman, M.Sc., Ph.D.; B. J. F. Ralph, B.Sc., Ph.D., A.A.C.I.; A. B. Walkom, D.Sc.; and W. L. Waterhouse, C.M.G., M.C., D.Sc.Agr., D.I.C.

Auditor: S. J. Rayment, F.C.A.

A cordial vote of thanks to the retiring President was carried by acclamation.

LINNEAN SOCIETY OF NEW SOUTH WALES.

GENERAL ACCOUNT. Balance Sheet at 29th February, 1960.

LIABILITIES.

	£	s.	d.	£	s.	d.
Accumulated Funds—						
Amount received from Sir William Macleay during his lifetime ..	14,000	0	0			
Further sum bequeathed by his will	6,000	0	0			
				20,000	0	0
Contingencies Reserve				14,367	11	4
				34,367	11	4
Current Liabilities—						
Bookbinding Account	1,127	10	1			
Income Account	1,115	17	5			
Suspense	56	9	7			
				2,299	17	1
				£36,667	8	5

ASSETS.

	£	s.	d.	£	s.	d.
Fixed Assets—						
Commonwealth Loans, at cost ..	15,048	10	0			
Debentures:						
Metropolitan Water, Sewerage and Drainage Board, at cost	5,344	7	6			
Science House (one-third share), at cost	14,835	4	4			
				35,228	1	10
Current Assets—						
Cash in Hand	10	0	0			
Commercial Banking Co. of Sydney, Ltd.	1,429	6	7			
				1,439	6	7
				£36,667	8	5

INCOME ACCOUNT. Year Ended 29th February, 1960.

	£	s.	d.	£	s.	d.
To Salary				730	10	0
,, Printing Proceedings	2,239	7	4			
,, Printing Reprints	563	9	0			
,, Blocks	367	17	4			
				3,170	13	8
,, Insurance				14	1	3
,, Postage	101	0	2			
,, Petty Cash	32	8	11			
				133	9	1
,, Audit	16	16	0			
,, Printing and Stationery ..	107	18	11			
,, Expenses	119	19	5			
,, Cleaning	62	17	6			
,, Bank Expenses	2	17	3			
,, Library	38	2	11			
				348	12	0
,, Balance to 1960-61				1,115	17	5
				£5,513	3	5

	£	s.	d.	£	s.	d.
By Balance from 1958-59				660	4	4
,, Subscriptions:						
1959-60	419	18	0			
Arrears	63	0	0			
In Advance ..	16	16	0			
				499	14	0
,, Entrance Fees				9	9	0
,, Interest				929	1	6
,, Science House				1,447	15	6
,, Rent				21	10	0
,, Sales				511	9	3
,, N.S.W. Government Grant ..				200	0	0
,, Fellowships Account (surplus income at 29th February, 1960, transferred)				698	11	11
,, Bank Expenses				2	18	2
,, Sale of Reprints				531	6	9
,, Postcard Sales				1	3	0
				£5,513	3	5

A. B. WALKOM,
Hon. Treasurer.

LINNEAN SOCIETY OF NEW SOUTH WALES.

LINNEAN MACLEAY FELLOWSHIPS ACCOUNT.

Balance Sheet at 29th February, 1960.

LIABILITIES.

	£	s.	d.
Accumulated Funds—			
Amount bequeathed by Sir William Macleay ..	35,000	0	0
Surplus Income Capitalized	21,635	3	1
	£56,635	3	1

ASSETS.

	£	s.	d.	£	s.	d.
Fixed Assets—						
Commonwealth Loans, at cost ..	30,449	0	0			
Debentures:						
Metropolitan Water, Sewerage and Drainage Board, at cost	17,156	14	9			
Rural Bank of N.S.W., at cost	2,172	15	0			
Loan on Mortgage	6,035	0	0			
				55,813	9	9
Current Assets—						
Commercial Banking Company of Sydney Ltd.				821	13	4
				£56,635	3	1

INCOME ACCOUNT. Year Ended 29th February, 1960.

	£	s.	d.
To Salary of Linnean Macleay Fellow	666	13	4
,, Research Expenses	141	17	8
,, Balance, being Surplus Income transferred to			
General Account	698	11	11
,, Capital Account	791	9	0
	£2,298	11	11

	£	s.	d.
By Interest	2,298	11	11
	£2,298	11	11

AUDITOR'S REPORT TO MEMBERS.

I have examined the books of account and vouchers of the Linnean Society of New South Wales for the year ended 29th February, 1960, and certify that the above Balance Sheet and accompanying Income Account are correct and in accordance therewith, and in my opinion present the true state of the Society's affairs at 29th February, 1960, as shown by the books. Certificates of the investments have been inspected.

S. J. RAYMENT, F.C.A., Chartered Accountant, Auditor.

Sydney, 11th March, 1960.

A. B. WALKOM, Hon. Treasurer.

4th March, 1960.

LINNEAN SOCIETY OF NEW SOUTH WALES.

BACTERIOLOGY ACCOUNT.
Balance Sheet at 29th February, 1960.

LIABILITIES.	£	s.	d.	£	s.	d.	ASSETS.	£	s.	d.	£	s.	d.
Accumulated Funds—							Fixed Assets—						
Amount bequeathed by Sir William Macleay	12,000	0	0				Commonwealth Loans, at cost ..	15,320	0	0			
Accumulated Income Capitalized ..	6,310	0	0				Debentures:						
Research Fund	10	0	0				Metropolitan Water, Sewerage and Drainage Board, at cost ..	800	0	0			
				18,320	0	0	Loan on Mortgage	2,200	0	0			
											18,320	0	0
Current Liability—							Current Assets—						
Income Account at 29th February, 1960				196	8	0	Commercial Banking Company of Sydney, Ltd.				196	8	0
				£18,516	8	0					£18,516	8	0

INCOME ACCOUNT. Year Ended 29th February, 1960.

	£	s.	d.		£	s.	d.
To University of Sydney (towards salary of Lecturer)	700	0	0	By Balance from 1958-59	86	19	7
,, Insurance		13	5	,, Interest	810	1	10
,, Balance to 1960-61	196	8	0				
	£897	1	5		£897	1	5

AUDITOR'S REPORT TO MEMBERS.

I have examined the books of account and vouchers of the Linnean Society of New South Wales for the year ended 29th February, 1960, and certify that the above Balance Sheet and accompanying Income Account are correct and in accordance therewith, and in my opinion present the true state of the Society's affairs at 29th February, 1960, as shown by the books. Certificates of the investments have been inspected.

S. J. RAYMENT, F.C.A., Chartered Accountant,
Auditor.

Sydney, 11th March, 1960.

A. B. WALKOM,
Hon. Treasurer.

4th March, 1960.

PRESIDENTIAL ADDRESS.

CONCERNING SPILITES.

By T. G. Vallance.

(Five Text-figures.)

[Delivered 30th March, 1960.]

Introduction.

If petrographers were to take a cue from their palaeontological colleagues they might place spilites among a group of problematica. Certainly these rocks, diverse in their occurrence, in their mineralogy and in their composition, provide more than ordinary difficulties to those who wish to classify them. Nevertheless, spilities constitute a group of rocks in which this Society should have more than a passing interest. It was one of our former members, the late Professor W. N. Benson, F.R.S., who first drew attention to the extensive occurrences of spilites in northern New South Wales. Much of Benson's work on these rocks was carried out while he was a Macleay Fellow, and his results, which still command the attention and admiration of petrologists throughout the world, were published in a series of papers in our Proceedings.

After Benson's departure for New Zealand in 1917, the investigation of spilites in Australia lapsed and it is only within the last ten years or so that local interest in these rocks has revived. In 1951, Scott published the first of a group of important papers on spilites in Tasmania and during the past couple of years I have been working over Benson's ground at Nundle.

The more spilites one looks at or reads about the more one is impressed by their widespread distribution, their diversity, and the almost equal variety of theories proposed to account for their genesis. These are the matters I wish to discuss this evening. Because a large number of important works on spilites are not easily available to local petrologists, I have concentrated on collecting information about foreign occurrences.

It seems generally to be believed that the term spilite was introduced by Alexandre Brongniart, the great French mineralogist and ceramist, in 1827. However, it appears (in the form spillite) in an article by de Bonnard published in 1819 with a note that the name had already been proposed by Brongniart in a first course of geology. Whether this course was published or was merely a set of lectures is unknown to me, but at least the term was in use by 1819.

Brongniart (1827) offers no indication as to the etymology of the word spilite, but it seems to have been derived from the Greek σπιλος, meaning spot or blemish. Variolite (from the mediaeval Latin *variolae* = smallpox) has rather similar connotations, but a history going back at least to the *lapis variolatus* listed in a posthumous work of Aldrovandus (Ambrosinus, 1648). Aldrovandus mentions examples from India, and from Lucca in Italy, and gives two woodcuts which are singularly uninformative. In any case, the material, whatever it was, was noted mainly for its supposed medicinal virtues. The reader interested in the early history of variolite should consult Cole and Gregory (1890). Of more immediate interest in the spilite story is the discovery about 1780 in Dauphiny, by Lamanon, later the naturalist with Lapérouse on his Pacific voyage, of a rock called the *variolite du Drac*. This material which Lamanon considered to be a lava—a view bitterly attacked by his contemporaries—was later taken by Brongniart as one of his type spilites.

The rocks classed by Brongniart (1827) as spilites were characterized by the presence of nodules of calcite, and sometimes of agate, in a base (*pâte*) of aphanite.* With the crude chemical information at his disposal Brongniart noted that the aphanite base had, at least in some cases, a composition akin to that of basalt. Disseminated through this base were chlorite, pyroxene, amphibole, feldspar, with epidote and mica rare to very rare, while amethyst, agate, jasper, prehnite, malachite, native copper, stilbite, analcite and talc are mentioned as accessories occurring in patches. Five varieties of spilite were recognized, namely, (1) *spilite commun*—"compact, dark green or purplish brown-red base; round calcareous nodules, sometimes white, sometimes red, sometimes accompanied by agate nodules"; (2) *spilite bufonite* [toadstone]— "black base; round calcareous nodules. It hardly differs from the preceding"; (3) *spilite zootique*—"portions of crinoids [*entrôques*] mixed with calcareous nodules. Base calcareous"; (4) *spilite veiné*—"base of aphanite, with veins and small grains of sparry calcite"; (5) *spilite porphyritique*—"determinable crystals of feldspars, etc., in the base, with calcareous and agate nodules". Each variety is illustrated by examples mainly from Europe.†

It must be realized that Brongniart's classification of rocks is essentially mineralogical and based on features observable in the hand specimen; there are no genetic implications in this scheme. In fact, the several rocks grouped as varieties of spilite almost certainly had quite diverse origins. The examples noted include rocks which we would now call clastic sediments; the *spilite veiné* (= Schalstein) from Dillenburg, as we shall see later, may be pyroclastic in character. Despite the apparent detail in Brongniart's descriptions, the difficulty of accurate mineral identification in fine-grained rocks in those "pre-microscope" days must have been great. A considerable number of fine-grained dark-coloured rocks spotted with calcareous nodules would probably have qualified for the name spilite as used originally. There is no suggestion in Brongniart's work, despite Daly's (1933) claim, that the original spilites were considered to be albitized. Such views were not advanced until well after Brongniart's time.

Brongniart introduced this new term mainly to avoid the confusion associated with the names variolite and amygdaloid. He had himself earlier (Brongniart, 1813) grouped as variolites the rocks he now (1827) proposed to call spilites. In his revision the term variolite was transferred to the rocks called amygdaloids in 1813. De Bonnard (1819) uses "spillite" and amygdaloid as synonyms. Spilite and variolite are used in the "revised" sense by Brongniart (1827), but in the following year he recommended that the name variolite be dropped.

Brongniart's hope of reducing terminological ambiguity was not realized. For one thing, the name spilite was not generally accepted outside France, and with this limited use synonyms or partial synonyms proliferated. Names such as amygdaloid (or mandelstein), variolite, trapp, greenstone, and even vakite or wacke continued to be applied to rocks which Brongniart would have called spilites. In the French literature we note an increasing tendency for the name spilite to be restricted to the type known as *variolites du Drac* (Brongniart's *spilites communs*), although as late as 1857, Delesse refers to certain lime-bearing argillaceous rocks affected by contact with "trappean rocks" as spilites. Brongniart had distinguished between spilites and melaphyres according to supposed mineralogical differences in the bases of the two rocks. Melaphyres, he considered, had a base of amphibole in contrast to the aphanite bases in spilites. The difficulties in applying these criteria are apparent. A more

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* The word *aphanite*, due to Haüy, was applied at that time to a specific rock material. According to Haüy's definition, aphanites were compact rocks of homogeneous appearance, dark green or black, with constituents indiscernible to the naked eye. Haüy considered them to be made of amphibole and feldspar intimately mixed.

† Under variolite, Brongniart (1827) lists an example from King Island, Bass Strait—a specimen probably collected during the Baudin expedition (1800-1804).

widely accepted view, that of Buch (1830), regarded melaphyre as a synonym for augite porphyry (porphyrite), a rock which, in fact, was called spilite by Élie de Beaumont (according to Hochstetter, 1864). In the works of the mid-19th century German lithologists (e.g., Naumann, 1850; Cotta, 1862), spilites are usually regarded as melaphyres.

The introduction of thin section petrography in the second half of the century led to considerable refinements in the techniques of mineral identification and fabric investigation. However, as far as the nomenclature of basic rocks was concerned, the advantages of this newly acquired precision may not be very obvious. Both Rosenbusch and Zirkel, the master petrographers of the 19th century, retained the notion derived, one supposes, originally from Werner, that relative age was an important criterion. Thus, according to Rosenbusch (1901), the terms basalt, melaphyre and diabase, relating to effusive plagioclase-augite rocks, had certain time significance, diabase being the oldest geologically while basalt was of most recent (Tertiary and post-Tertiary) origin. Rosenbusch (1901) contrasts granular diabases with compact (fine-grained) diabases or spilites. The latter were separated from the melaphyres, though he was forced to admit that the distinction between diabase and melaphyre "was becoming obliterated". In addition to noting the fine-grained character of his spilites, Rosenbusch also drew attention to their frequent glassy patches and the tendency for feldspar and pyroxene to occur as radiating units. Variolites he regarded as types of spilite in which this radiating character was especially apparent. Earlier (Rosenbusch, 1887) he had recognized spilite as a plagioclase-pyroxene rock, rich in amygdules, and sometimes with variolitic fabric and a few phenocrysts. His definition of 1887 has spilite equivalent to an augite porphyrite. The rocks called spilites under both the 1887 and 1901 definitions are fine-grained with fabrics of the type called microlitic by Michel-Lévy (1889), in contrast to the fabrics of ophitic and granular diabases. Zirkel appears to have avoided the term spilite and simply refers the rocks called spilites by the French to his amygdaloidal diabases (Zirkel, 1894). If we accept the interpretation that Brongniart's "nodules" (noyaux) are amygdules there is really no great difference in character between the spilites of Rosenbusch and the common spilites of the original definition. Only the implications of age are foreign. By analogy with the porphyrites or diabases with which the spilites were grouped it would seem that Rosenbusch regarded the feldspars of his spilites as calcic.

English-speaking geologists made little or no use of the term spilite during the 19th century. Rocks which would have been called spilites by the French were usually known as greenstones. In view of this lack of interest it is somewhat surprising to find Johnston (1888, p. 370) in his work on Tasmania listing spilite as a variety of dolerite (basalt, trap). Although no examples are given, this is almost certainly the first appearance of spilite in the literature of Australian geology. In 1893, Bonney and Raisin published a short account of some older Palaeozoic fine-grained basic rocks from the island of Jersey. These rocks had been called spilites by earlier French workers, and this name Bonney and Raisin accepted, though not without qualification. Bonney and Raisin noted that the spilites showed signs of extensive alteration of the original feldspars and ferromagnesian minerals. The rocks were regarded as the products of a vulcanism contemporaneous with the associated sediments which included breccias and banded green flinty argillites. This short study by Bonney and Raisin was most opportune. Geikie had recently drawn the attention of geologists to the problems posed by the older volcanic rocks of Britain. Some years before, the so-called greenstones of Cornwall had been described in a series of papers by J. A. Phillips. Ellipsoidal structures in some of these Cornish greenstones had been known at least since the time of de la Beche, and in 1894 Teall noted the common association of ellipsoidal greenstones and radiolarian rocks at Mullion Island, Cornwall. To describe the ellipsoidal nature of these greenstones believed to be of submarine origin Teall coined the term "pillow structure"—hence the name pillow lava for effusive rocks exhibiting this character. During the period of Teall's directorship (1901–1914), a good deal of

work was done by the officers of H.M. Geological Survey, especially in Cornwall, on pillow lavas and associated intrusive rocks. The name spilite was adopted by the Survey in 1907 to designate these pillow lavas (Flett, 1907), and in 1911, Dewey and Flett published their review on British pillow lavas or spilites. This latter work deserves special attention because of its great influence on subsequent studies. Dewey and Flett pointed out that the rocks called spilite in Britain often show signs of decomposition. The feldspars are always rich in soda, and although pyroxenes are seen occasionally, it is more common to find them completely replaced by secondary products such as chlorite, calcite and epidote. Following Bailey and Grabham (1909) the sodic feldspars were regarded as of secondary origin. Fresh olivine is never present. Dewey and Flett observed that many of their spilites contain devitrified glassy material. Porphyritic varieties are rare, and most of the feldspar occurs as microlites or fine laths sometimes arranged in fluidal fashion and occasionally in radiating groups. The few chemical analyses available to Dewey and Flett indicated markedly high soda, carbonate and water and low potash contents compared with those of other basic rocks. In calling these sodic rocks spilites Dewey and Flett claimed that they are of the same type as the rocks called spilites by Brongniart. This is, in fact, true, but it must be realized that the mineralogical criteria, especially that of sodic feldspars, and the chemical features of high soda and low potash, used by Dewey and Flett, effect a considerable restriction. In addition, Dewey and Flett endowed the term with certain genetic features of a distinctly hypothetical nature. The pillow lavas or spilites were believed to form part of a group of rocks, called the spilitic suite, which could be "clearly distinguished from the Atlantic and Pacific suites". This spilitic suite included types ranging from ultrabasic to acid in composition and was regarded as typical "of districts that have undergone a long-continued and gentle subsidence, with few or slight upward movements, and no important folding". Dewey and Flett considered the spilites as submarine lavas, and the sodic feldspar found both in them and in associated intrusive diabases resulted from the albitization of pre-existing calcic feldspars.

The hypothetical views of Dewey and Flett have been rejected by many workers. Eskola complained in 1925 that "to use the term spilite would mean to accept a theory", and accordingly preferred "longer but more descriptive and more neutral mineralogical names such as ophitic albite-clinopyroxene rock". Misgivings about the use of the name had been expressed earlier by Benson (1915a).

The important diagnostic features listed by Dewey and Flett, namely, sodic feldspar (albite or sodic oligoclase) and high Na_2O, H_2O and CO_2, with low K_2O are recognizable only by the use of special techniques. A spilite in the sense of Dewey and Flett cannot be recognized without laboratory examination. Pillow structures, commonly noted in spilitic rocks, are by no means characteristic of spilites. There are numerous records, for example, the pillow lavas on Mull, of normal basaltic pillow-bearing rocks. Again, we might point out here that pillow structures, though common in submarine lavas, are not restricted to these cases. Lewis (1914) argued that pillows might also form in subaerial flows and Stark (1938) has found evidence of this at Borabora in the Pacific.

Nevertheless, most recent workers, who have used the term spilite, tend to follow Dewey and Flett in so far as mineralogy and chemical composition are concerned. There are still some, however, who impose genetic restrictions. I have mentioned that Dewey and Flett believed that most of the albite in their spilites was of a secondary character; others have considered the albite of spilites to be primary. This matter will have to be considered in more detail at a later stage, but for the moment suffice it to say that the situation has given rise to some extraordinary contradictions. As an example, von Eckermann (1936) objected to the use of spilite as a name for certain greenstones in Sweden because they offer evidence of albitization of primary calcic plagioclase. On the other hand, Lehmann (1940) apparently declined to use the name spilite for rocks he called weilburgites because, among other things, the albite in them was not produced by albitization of a calcic feldspar. Van Overeem (1948) rejects as spilites those rocks

with secondary albite in which the albitizing solutions have been derived from an external source even though the composition of these rocks may be identical with that of "real" spilites.

In 1917, H. C. Sargent published an account of his studies on the Carboniferous lavas of Derbyshire, rocks known locally as toadstones and, in fact, called spilites (*spilites bufonites*) by Brongniart. Sargent claimed that these rocks were allied genetically to the spilites of Dewey and Flett, but, unlike the latter, contained appreciable amounts of both sodium and potassium, often carrying K-feldspar in addition to a sodic plagioclase. Sargent coined the term potash-spilite for these lavas. Shortly after the introduction of the term, Wells (1923) recommended that it be dropped, but in recent times Tomkeieff (1941) has not only used the term, but added what he considers to be another example. Basic rocks containing adularia and associated with sodic spilites in Timor have been called poenites by de Roever (1942). Many of the so-called weilburgites of the Lahn region are also rich in potash (Lehmann, 1949).

The name spilite has been used over a period in excess of fifty years for an important group of basic rocks in the Pre-Cambrian of Bohemia (e.g., Slavik, 1928; Kutina, 1955). These Bohemian spilites commonly have calcic feldspars (andesine or labradorite) and are so named because of their aphanitic fabric—a usage harking back to Rosenbusch's compact diabases. Backlund (1930) has also given the name spilite to fine-grained lavas containing andesine as the typical feldspar.

There appear to be four main criteria used in the recognition of spilites, namely, fabric, mineralogy, chemical composition and geological occurrence. Much of the confusion associated with the name spilite derives from the fact that various workers have emphasized different features. Most would agree that spilites are mainly basic rocks and usually occur as flows or shallow intrusions. Some, for example, Backlund (1932), insist that spilites belong to a particular tectonic environment, namely, that of the early "evolutionary" phase in a geosyncline. To Backlund it was a matter of secondary importance whether spilites contained albite or a calcic feldspar. Richards and Bryan (1924) applied the name spilite to a rock containing andesine because they claimed that the chemical composition of this rock was similar to that of known spilites; furthermore they argued that their spilite occurred with radiolarian cherts. We have already seen that Bohemian petrographers use the term spilite for rocks with a certain type of fabric. Dewey and Flett attempted to combine all four criteria in their definition.

Some would say that the variety of meanings attached to the name spilite is just too great for the term to be of any use (Johannsen, 1937). However, the fact remains that not only is it still used, but the list of examples of rocks called spilites increases annually. For the present discussion I propose to accept all spilites identified as such in the recent literature. It seems to me far better to start from this position than to set out by excluding types which do not satisfy the requirements of a preferred definition.

The Occurrence of Spilites.

Although spilitic rocks have not been recorded among the products of recent igneous action they are represented throughout most of the geological column. Archaean spilites are known from several parts of the world and recently Ramos (1958) has claimed that spilites of Pleistocene age occur in northern Brazil. Amstutz (1958) believes that spilitic rocks have decreased in frequency and volume during the period from the Pre-Cambrian to the Tertiary, though this, I feel, has yet to be demonstrated.

The reader of textbooks on petrology and structural geology may be excused for believing that spilites are exclusively the property of geosynclinal tracts and that, furthermore, these rocks belong to the early period of sinking and sedimentary accumulation within a eugeosyncline. Were we to follow Backlund, such, of course, would be the case. The majority of examples are indeed recorded from geosynclinal environments, but spilites are by no means so confined in occurrence. Epicontinental and even continental types are known and documented. Again, although many spilites

are effusive in character, some are definitely intrusive and apparently unrelated to effusive vulcanism.

Swiss geologists recognize an ophiolite association as representative of early magmatic activity in the Alpine orogen. These ophiolites occur typically in the Pennine nappes as concordant bodies among Mesozoic sediments now often metamorphosed to *schistes lustrés* and rich in porphyroblasts of albite. As used originally by Brongniart, the term ophiolite was applied to serpentines, but as a group name it now includes, as well as ultrabasic types, coarse-grained gabbroic rocks, fine-grained diabases, basic breccias, and greenschists probably derived from more than one variety of basic material (Cadisch, 1953). In general, more acid rocks such as rhyolites or keratophyres are missing, though a minor exception is noted by Jaffé (1955). Among the gabbros we have to recognize types with saussuritized basic plagioclase and types containing albite. Diabases seem to be the most abundant of the ophiolitic rocks and are apparently of effusive or very shallow intrusive character. Recently, pillow structures have been recognized in them (Vuagnat, 1948). Many of the diabases as well as the albite gabbros are now regarded as spilites (Jaffé, 1955; Vuagnat, 1954) and in some cases they are essentially unmetamorphosed. However, as dislocation has been intense in parts of the Pennine zone, it is hardly unusual to find metamorphosed units of the ophiolite group. Bearth (1959) has recently described from the western Alps eclogites and glaucophane schists which retain traces of an original pillow lava character. Greenschists with compositions similar to the Alpine spilites are known from the Grisons (Grubenmann, 1909; Roothaan, 1919), but many greenschists are non-spilitic.*

Accompanying the ophiolites we find typically marine sediments including breccias, radiolarian cherts and lime-bearing rocks of Flysch type. Although the term is not used widely by Alpine geologists, many of these Flysch-type rocks may be regarded as greywackes. Many of the breccias are made up largely of igneous material and are really ophiolite breccias (Jaffé, 1955). The radiolarian rocks, in particular, have received a great deal of attention from geologists. Once thought to belong exclusively to an abyssal environment (e.g., Steinmann, 1927), there is now some evidence, not only in the Alps (see Cadisch, 1953, pp. 233–234), but in many other places (Tromp, 1948), that radiolarian rocks may have formed in shallower water. Nevertheless, it must be recognized that the ophiolites of the Pennine zone appear to belong to an axial geosynclinal environment. Vuagnat (1954) envisages a depth of sea water up to about 1,000 metres in this trench. There can be no doubt because of the close association with marine sediments that the recorded ophiolitic spilites represent contemporaneous submarine igneous activity. However, the Eocene-Oligocene Taveyannaz Sandstone in the north helvetic Flysch contains a great deal of spilitic material. According to Cadisch (1953), Vuagnat (1943) has recognized, using supposed textural criteria, spilites of both submarine and subaerial types as fragments in the sandstone. Although the subaerial spilites cannot be related to any known eruptive rocks in the western Alps, Vuagnat considers all the volcanic fragments as connected with ophiolites of the Pennine zone.

The association of radiolarian rocks and ophiolites has been recognized for many years, at least, in fact, since the 1880s when Pantanelli and Lotti independently drew attention to it in Tuscany. Steinmann (1905, 1927) later emphasized that the association was common not only in the Apennines but also in the Swiss Alps. Steinmann's work is now well known and the association dignified by the name "Steinmann's Trinity" referring to the grouping of serpentines, spilites and radiolarian cherts (Hess, 1955). As Steinmann recognized three main groups among the ophiolites (serpentines, gabbros and diabase spilites), the nickname is not especially illuminating. Although we are

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* Among the greenschists of the (? Pre-Permian) Casanna schists in Valais, Vallet (1950) distinguishes ovardites (albite and chlorite) and prasinites (albite and chlorite + Ca minerals). Vallet considers the ovardites only as metamorphosed spilites. Prasinites are also common in the ophiolite group.

not concerned at the moment with the genesis of spilites, it should be remembered that Steinmann believed that all three ophiolite members were derived from the same magmatic source and, further, that there was a succession in time with serpentines earliest and spilites latest. This succession does, in fact, exist in parts of the Apennines. Van der Waals (1946), for example, finds this order in the Upper Jurassic rocks near Spezia. Here radiolarian rocks are associated with the ophiolites, but are claimed to ante-date the spilite members. Steinmann's succession is not, however, universal. In the ophiolites of Chablais (Haute Savoie), for example, the ultrabasic rocks are later than the spilitic members, with the gabbros in this case being quite subordinate (Jaffé, 1955).

The ophiolite type of spilite occurrence is by no means confined to the Alpine regions. We have already mentioned examples in the Apennines of Italy. Netelbeek (1951), Ritsema (1952) and Routhier (1946) have described similar cases in Corsica. Very considerable thicknesses of ophiolitic material were apparently extruded during the Jurassic in the Dinaric geosyncline of N.W. Greece (Brunn, 1954). Brunn records spilites, basalts and even andesites among the fine-grained members of his ophiolite suite. Radiolarian rocks appear at the contacts with the fine-grained ophiolites or tuffs. It is of interest to note that in this case the ophiolitic material apparently issued marginally to the geosyncline, and as well as spreading towards the axis it also extended towards what was probably foreland. From the eastern seaboard of the Mediterranean, Dubertret (1954) has described an enormous mass, up to 3,000 metres in thickness, of ophiolitic material ranging upwards from peridotites and serpentines at the base to gabbros, to uralitized basalts and finally to "sakhalavites", sometimes partly glassy and with pillow structures. These "sakhalavites" are associated with radiolarian rocks, and although the exact nature of the sakhalavites is not clear from the work cited, Rittman (1958) claims that they (he calls them "sakavalites") are spilitic. Dubertret regards them as submarine lavas which acted as a cover for the successive intrusion of the gabbros and ultrabasic types. The field evidence seems to indicate a location in what was a foreland margin and not the typical axial, geosynclinal zone.

Ophiolitic spilite associations are common in those orogenic zones which suffered Tertiary folding—the so-called alpine zones. Van Bemmelen (1949), for example, records many typical occurrences in the Indonesian region. Recently, Reinhard and Wenk (1951) have added considerably to our knowledge of the ophiolites in the pre-Tertiary Danau Formation of North Borneo. Their ophiolite group is essentially unmetamorphosed and occurs, as usual, with radiolarites, argillites and Flysch-like sandstones. The spilites are regarded as submarine lavas, but pillow-structures are rare. Manganese deposits are associated with radiolarian cherts and spilites of early Tertiary age in North Borneo (Stephens, 1956).

The potash spilites or poenites of Permian age in Timor (de Roever, 1942) occur with olivine basalts, soda spilites, trachybasalts, alkali trachytes and alkali rhyolites. According to van Bemmelen (1949), all of the Permian sediments of Timor are of neritic facies and the poenites, etc., belong to a "weakly Atlantic suite" within these sediments. On the other hand, post-Permian eruptive rocks in Timor are ophiolitic and include spilites (sodic) with ultrabasic and other basic types as well as andesites and keratophyres. The ophiolites formed at a time of strong down-warping.

The spilites described by Greenly (1919) from the Gwna and New Harbour Groups of the Mona complex in Anglesey represent early (Pre-Cambrian) activity in the Caledonian geosyncline. The Gwna Group contains detrital sediments of Flysch type (Vuagnat, 1949a; Termier and Termier, 1956b, p. 270), and according to the latter authors these detrital sediments and the associated jaspers, spilites and tuffs accumulated near the margins of a filling geosyncline. Pillow structures are well preserved in many of the spilites. Greenly records a few keratophyres in the Gwna beds. Subordinate rhyolitic material, mainly as ejectamenta, occurs with the spilites, while later intrusive bodies ranging from serpentinites to alkali granites also belong to the complex. Locally, spilites have been converted to glaucophane rocks. Early igneous activity in the

Caledonian geosyncline is also represented by the more or less metamorphosed Dalradian spilites (and albite diabases) of the Tayvallich Peninsula, Argyllshire (Flett, 1911; Vuagnat, 1949b). Again, pillow structures are preserved in the spilites and basic rocks predominate. Flett records occasional keratophyres and soda felsites. Dalradian basic pillow lavas, which may or may not be spilitic, have also been reported from Ireland (McCallien, 1936).

Spilitic rocks make their appearance again within the Ordovician succession of the Caledonian chain in Britain. At Ballantrae, Ayrshire (Balsillie, 1932, 1937; Bloxam, 1960), pillowy spilites are closely associated with agglomerates, tuffs, radiolarian cherts and graptolitic shales. These rocks are invaded by intrusive bodies ranging from serpentinites to granites. By way of contrast, the Ordovician spilites in Wales, also within the Caledonides, belong to a rather different association. Early Arenig vulcanism in this region produced mainly andesites with some basalts and dacites. However, pillowy spilites are found in the Arenig of Ireland (Gardiner and Reynolds, 1912, 1914). Extensive spilitic bodies are associated with Llanvirnian marine sediments (chiefly black graptolitic shales). The Fishguard Volcanic Series, described by Thomas and Thomas (1956), reaches a thickness of about 3,600 feet near Strumble Head, Pembroke-shire. Pillow-bearing spilites as well as columnar spilites, spilitic breccias and agglomerates, "oligoclase basalts of Mugeary type", feldspathic sands, ashes and cherty rocks occur here between rhyolitic horizons. Mugearites are also said to occur as lavas on Skomer and adjacent parts of Pembrokeshire, with albite-oligoclase-bearing basic rocks of doubtful affiliations (and called marloesites and skomerites) as well as trachy-basalts, keratophyres and soda rhyolites. These rocks were subaerial in character (Thomas, 1911). Many of the basic lavas in the Ordovician of North Wales are regarded as spilitic and carry pillows. However, it must be emphasized that basaltic rocks with normal calcic feldspars occur with these spilites. Andesitic and rhyolitic (often sodic) lavas, with very considerable thicknesses of acid fragmental material recently recognized as ignimbrites, are commonly found with these spilites. East of Rhobell Fawr, Merionethshire (Wells, 1925), spilitic lavas are locally associated with variolitic basic lavas containing labradorite. Followed northwards, the submarine spilites give way to subaerial hypersthene andesites (Fearnsides, 1905). Spilitic pillow lavas occur with acid lavas and tuffs in the Cader Idris area. Davies (1959) has recently described these rocks briefly and notes that intrusive doleritic bodies associated with the basic lavas vary from "little altered, ophitic augite dolerites, with andesine or even labradorite, to very highly autometasomatic spilitic rocks". The occurrence of albite-bearing basic intrusive rocks with spilitic lavas is, in fact, quite common in the Welsh Ordovician. Some of these dolerites have converted the invaded mudstones into adinoles.

The Welsh Ordovician spilites were preceded by andesites, and were succeeded by andesites during Llandeilo times. The spilites at Cader Idris and at Llanwrtyd (Stamp and Wooldridge, 1923) are high in the stratigraphic sequence. The Welsh spilites appear to have been submarine flows or shallow intrusives, and the association of spilites with subaerial acid flows and ash beds suggests that some of the spilites may have formed in fairly shallow water near shorelines. The differences between these occur-rences and those of the ophiolite spilites are obvious. Not only are serpentine bodies apparently absent in the Welsh Ordovician, but there is a vast development of inter-mediate and acid lavas. On the other hand the Ordovician spilites at Ballantrae may be ophiolitic. Ultrabasic and spilitic rocks occur in the Trondhjem area of Norway (Carstens, 1924) and are succeeded by plutonic intrusions of trondhjemite belonging to the "revolution phase" in the history of the Caledonides. Some of the greenschists at Sulitelma, Norway, are spilitic in composition (Vogt, 1927). In Södra Storfjället, southern Lapland, Beskow (1929) has found keratophyres with basic effusives, at least akin to spilites, in sediments supposedly of Silurian age. Backlund (1932) records spilites, albite diabases, and keratophyres in the "Caledonian" chain of east Greenland, though more recent workers regard these rocks as Devonian in age.

In Fennoscandia, spilites or spilitic greenstones have been recognized in several of the Pre-Cambrian mountain chains.   Near Petsamo, in the western part of the Saamide chain of the Kola Peninsula, a region discussed by von Bubnoff (1937), spilitic pillow lavas occur with tuffs, diabases and sandstones and conglomerates of molassic type (Termier and Termier, 1956b. p. 238).   If this interpretation is correct and molassic sediments occupy a place here comparable with that of the Alpine molasse then we have another variation in the pattern of spilite occurrences.   The spilitic greenstones of the Kiruna area of Sweden (Sundius, 1915) occupy a part of the Svecofennide chain according to Termier and Termier.   Pillow structures are still evident in these rocks despite the metamorphism.   At Kiruna, a wide variety of more acid igneous rocks including keratophyres (sometimes called syenites, e.g., by Geijer, 1916) and quartz porphyries is associated with greenstones, tuffs, breccias, cherts and impure limestones.   Gjelsvik (1958) has described spilitic greenstones representing extensive basic vulcanism in the late Pre-Cambrian Karelic geosyncline in northern Norway.   Intrusive albite-rich rocks (diabases, soda-granites and albite syenites) also occur here.   The spilites from south-eastern Karelia described by Eskola (1925) are well known.   Near Petrozavodsk, Karelian A.S.S.R., pyroxene-bearing spilites appear mainly as submarine effusive bodies, often agglomeratic and sometimes with pillows, in an environment of shales and dolomites.   Basaltic rocks with calcic feldspars occur with the spilites.   To the north, hornblende-bearing assemblages are commoner and with increase in metamorphic grade there is a transition to amphibolites.   The amphibole-bearing spilites occur typically as thin bodies invading quartzites; signs of effusive action are rare.   Apart from rare granophyric albite-hornblende rocks associated with the spilites, this region seems to have been characterized by basic igneous activity. Further north, around Seg Ozero in Karelia, pillowy spilitic flows, succeeded by quartz keratophyres, may have been poured out during marine regressions (Kharitanov, 1937). The environment here seems to have been epicontinental.

Spilitic rocks occur in various associations in the Hercynian or Variscan chain of western Europe.   The well-known examples in the Devonian and Carboniferous of Devon and Cornwall (Dewey and Flett, 1911; Flett, 1907) are essentially pillow lavas with related fragmental rocks.   Acid lavas, variously called sodic rhyolites or quartz keratophyres, are quite subordinate.   A considerable variety of minor intrusive rocks ranging in character from basic to ultrabasic (picrites) are found with the spilites. Some of the intrusive dolerites contain albite as the typical feldspar, but quartz-bearing dolerites, also regarded by Dewey and Flett as belonging to the same epoch as the spilites, are notable because they contain labradorite.   Adinoles are common at the contacts with albite dolerites (Agrell, 1939).   In this region, cherts and detrital sediments, regarded as of Flysch-type by Hendricks (1939), are associated with the spilites which seem to have accumulated well within the geosynclinal zone.   Pillowy spilites with keratophyres and tuffs have been reported from Belgium (Corin, 1935). In the Rhenish Schiefergebirge, also within the Hercynian chain, basic lavas (often with pillow structures) and intrusives are associated with abundant keratophyric rocks. Examples are to be found among the Devonian rocks of Sauerland and the Lahn region of Nassau (e.g., Götz, 1937; Lehmann, 1952).   Perhaps a rather similar association exists to the east in the Fichtelgebirge from whence came the original keratophyres (Gümbel, 1874).   The magmatic rocks of the Lahn area have been the objects of considerable petrological study, partly, I suppose, because of the associated iron and manganese deposits.   In older works (e.g., Brauns, 1909) the basic rocks are called essexites, while more recent investigators have called them spilites, keratophyric spilites or weilburgites.   This latter term, due to Lehmann, was introduced in the belief that the rocks are primary crystallization products (Lehmann, 1949, 1952a). Such genetic interpretations have been combated by Hentschel (1952a, b, 1953) and others.   The weilburgites (or spilites) are associated mainly with the manifestations of the second of three great cycles of effusive or subeffusive igneous activity (Pilger, 1952).   Keratophyric rocks predominate in the first (Lower Devonian) cycle.   After

this initial acid activity, keratophyres occur with weilburgites, basaltic lavas and *Schalsteine*, mainly in the upper Middle Devonian. The so-called *Deckdiabas* in the Lower Carboniferous concludes the group. Pyroclastic rocks are abundant throughout the sequence, though Lehmann (1952a) claims that weilburgite tuffs are missing. The *Schalsteine* present special problems about which controversy has continued for many years (see, e.g., Lehmann, 1952c; Hentschel, 1952b). The term *Schalstein** is an old one dating from 1789 (Lehmann, 1933), and like many old terms seems to have had various meanings. These rocks have been regarded as brecciated magmatic rocks, as tuffs, as redistributed tuffs, or as altered basic rocks, though many of them are now highly siliceous. According to Pilger (1952) the Devonian eruptive rocks are connected with a rapidly sinking part of the Rhenish trough. In the graben-like trough of the Lahn area subsidence was apparently very rapid. Thick accumulations of sediments in the Middle Devonian here carry essentially pelagic organisms. The final group of eruptive rocks, the *Deckdiabas*, includes pillowy diabases and is associated with greywackes and radiolarian cherts (lydites). Pilger considers the *Deckdiabas* as ophiolitic in character.

Chenevoy (1958) has recently recognized spilites and keratophyres with basic and ultrabasic intrusives and Flysch-type sediments in the Massif Central of France. The calcic feldspar-bearing spilites in the Algonkian of Bohemia (Slavik, 1928, 1945) deserve special mention. In the region of Kladno (Cepek, Hynie, Kodym and Matejka, 1936), for example, granular diabases, variolites and glassy breccias are found with these spilites in a geosynclinal succession of greywackes and cherts (phtanites). The spilite-greywacke-chert association is preceded by deep-water facies and succeeded by coarse detrital sediments. The spilites are thought to have solidified under only moderate depths of sea water. Pillow structures are common; recently submarine pillow lavas with cherts have also been found in the Ordovician of western Bohemia (Hejtman, 1954). Keratophyres appear in the Cambrian of this region, but do not occur with the spilites of the Algonkian. ·

In Russia, there are numerous occurrences of spilitic rocks in both the Uralian (Hercynian) and Caucasian (Alpine) chains. Spilites with diabases, gabbros, and albitophyres (keratophyres?) appear first in the Lower Ordovician of the Urals. This activity continued at intervals through the Silurian and Devonian into Carboniferous times. Signs of andesitic-dacitic vulcanism during this period are also found in parts of the Urals. Ultrabasic bodies were emplaced during the Devonian and Carboniferous, but the spilites do not seem to be typically ophiolitic. Mashkovzev (1933) has described an area in the northern Urals where basic pillow lavas and spilites are the most abundant igneous rocks in a succession with greywackes and other geosynclinal sediments. In this locality pre-Tournaisian basic effusives are commonly albitic, whereas the Carboniferous rocks often contain labradorite. Important sulphide deposits have been found with spilites and keratophyres in both the northern and southern Urals (Zavaritsky, 1943a, b, 1945, 1946; Kurshakova, 1958). Ronov (1946) has attempted to correlate quantitatively the various effusive rocks with tectonic events in the Uralian geosyncline. The Devonian spilites reported by Backlund (1930) from Nowaya Zemlya, on one of the northern branches of the Uralian chain, contain andesine and occur with picrites, quartz keratophyres and albite diabases. In general the intrusive types are richer in sodic feldspar than the effusives, though there does seem to be a regional variation in the character of the diabases. Kupletsky (1932) claims that albite diabases are confined to the northern island, normal diabases occurring in the southern island. Cissarz (1928) considered the sediments associated with the effusive spilites of Nowaya Zemlya to be of epicontinental marine type, while Backlund (1930) thought that the spilites might even have been subaerial.

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* Dewey and Flett (1911) used the word to denote sheared spilites. In Japan, the name is applied to basic tuffs of pre-Tertiary age (Takabatake, 1956).

B

What is now the Great Caucasus in the southern U.S.S.R. was the site of extensive vulcanism during Jurassic times. The area was then a trough adjacent to the Russian platform and the Lower and Middle Lias volcanic rocks are submarine in character. Later in the Jurassic, this geosynclinal trough was separated by a rising geanticline from the main Caucasian geosyncline. Loewinson-Lessing and Diakonova-Savelieva (1933) have recognized three cycles among the Jurassic igneous rocks at Karadagh in the Crimea, situated on the line of the Great Caucasus. The first cycle is of minor importance, but the second is marked by numerous flows, tuffs and agglomerates ranging in order of appearance from basic to acid. This cycle includes spilites, kerato-spilites (a new name), keratophyres, oxykeratophyres and palaeoliparites. Both spilites and keratospilites have pillow structures. The final cycle is represented mainly by intrusive bodies ranging from basalts to dacites and liparites.

Pichamuthu (1938, 1946b) claims that spilitic rocks and keratophyres occur in the Archaean Dharwar System of peninsular India. Pillow structures are recorded in the Jogimardi traps which Pichamuthu regards as spilitic. However, if these traps were formed immediately *after* an orogenic revolution, as Pichamuthu (1946a) suggests, this occurrence of spilite is unusual. Spilite, keratophyre and schalstein are repre-sented among the products of Palaeozoic and Mesozoic volcanic activity in Japan (Suzuki and Minato, 1954; Takabatake, 1956). They occur typically with greywackes, tuffs, and radiolarian cherts in geosynclinal associations. Takabatake considers that both spilites and basalts are represented as pillow lavas, spilites being especially common among the Mesozoic lavas. Manganese ores are found as layers in the cherts and tuffs and usually near contacts with the basic lavas.

Taliaferro (1943) has described Californian occurrences of manganiferous cherts associated with spilitic lavas in both the Amador and Franciscan-Knoxville Groups. The Amador Group (Jurassic; pre-Nevadan) consists largely of volcanics and cherty sediments. Spilitic pillow basalts are briefly noted by Taliaferro, but andesitic-dacitic vulcanism is more typical of the Amador. The post-Nevadan, late Jurassic, Franciscan occurring typically in the Coast Ranges is, by contrast, rich in coarse feldspathic greywackes. The vulcanism in the Franciscan is more basic in character and spilites are common, although in most cases they are now severely deformed. As ultrabasic bodies appear to be closely related in time to the basic vulcanism, this association is reminiscent of the Alpine ophiolites. Further north, in the Olympic Peninsula of Washington, Park (1946) records 30,000 feet of Eocene greywackes, argillites, volcanics, and limestones with manganese ores and ·jaspers. Spilitic pillow lavas are abundant and are thought to have formed in deep water. In the upper parts of the section, normal basalts occur. The preponderance of basic material here is in contrast to the extensive development of keratophyres with spilite in the Permian rocks of eastern Oregon, discussed by Gilluly (1935). Pillow structures are absent, but there is clear evidence that the association is marine and geosynclinal. This occurrence is of especial interest because of the development of trondhjemitic and albite granite bodies subsequent to the formation of the keratophyres. From the eastern side of the continent, Flaherty (1934) has recorded a thick succession of spilite, keratophyre, tuff, phyllite, quartzite and conglomerate invaded by plutonic bodies of quartz diorite and albite granite.

The Pre-Cambrian Keewatin lavas in Canada include ellipsoidal greenstones, andesites, dacites and rhyolites (Wilson, 1913, 1960; Satterly, 1941). They occur in sequences of arkoses, greywackes, argillites and conglomerates. Although the green-stones are not usually called spilites by Canadian geologists, they show many of the features of spilites; they are referred to as such by Termier and Termier (1956b).

Spilites were first recognized (on the Three Kings Islands) in New Zealand by Bartrum in 1936. This occurrence in which spilites are associated with keratophyre and sediments "of the greywacke facies" has recently been studied in detail by Battey (1955, 1956). Since 1936, spilites, always associated with geosynclinal sediments, have been found in both of the main islands. Late Palaeozoic (? Permian) spilites

are recognized in various parts of Southland. In each case spilites and albite diabases occur with greywackes and argillites. Keratophyres are commonly present, though at Mossburn (Reed, 1950) they are subordinate. Ultrabasic rocks invade the Mossburn Group in the latter area, but the age of these ultrabasic rocks is not really known, though Reed inclines to a belief in an ophiolitic association. Radiolarian cherts have also been found at Mossburn. In the Eglinton Valley (Grindley, 1958), ultrabasic rocks are apparently just older than the spilites. Wood (1956) has found albite granite invading spilites and keratophyres at Gore. Sodic granite also appears in the Eglinton Valley, but is older than the spilite; keratophyres in this area are also distinctly older than the spilites. Reed (1957) has found spilites unaccompanied by either keratophyres or ultrabasic rocks, in the Lower Mesozoic succession of the Wellington district. In this case the spilites occur with feldspathic greywackes, argillites, conglomerates, autoclastic breccias, jaspers and cherts belonging to the so-called Alpine Facies, a facies found along the main mountain chain in the South Island and probably representing the deepest part of the New Zealand geosyncline.

In Australia, records of spilites are confined to three States, Queensland, New South Wales and Tasmania. Examples are known only from Palaeozoic rocks, and in each case the spilites are related to geosynclinal activity.

Both Scott (1954) and Banks (1956) have reviewed the igneous action indicated by rocks in the Cambrian Dundas Group in Tasmania. Picrite basalt, olivine spilite, porphyritic pyroxene basalt, spilite, hornblende andesite or keratophyre, biotite kerato-phyre, quartz keratophyre and rhyolite, according to Banks, occur in this Group. Although the origin of the acid representatives has been much discussed, Banks considers most of them to represent originally acid lavas. Both Banks and Scott regard the series from picrite basalts to acid lavas as representative of a spilitic suite. The associated sedimentary pile is made up largely of greywackes, conglomerates, argillites, cherts and pyroclastic material. Ultrabasic rocks invade the Dundas Group, but their relation to the spilites is not clear. On King Island, Scott (1951a) has identified Cambrian spilites, picrite basalts, breccias and tuffs comprising a volcanic suite associated with tillite and varves. Massive, pahoehoe, aa, and pillow lavas are repre-sented, and Scott suggests that the pillows are developed where subaerial pahoehoe lava has flowed into lakes of glacial meltwater. On lithological grounds these lavas are correlated with those of the Dundas Group.

Stevens (1952) has found pillowy spilites with andesites, basalts, tuffs and breccias underlying massive and shaly limestones of Middle Ordovician age near Woodstock, N.S.W. The environment was probably geanticlinal. Ordovician albite-bearing pillow lavas also occur to the east, near the Abercrombie River, but in this case they appear in a thick sequence of greywacke-type sediments (pers. comm. from Mr. B. Hobbs). Spilites are known from both the Woolomin (Silurian-Devonian?) and Tamworth (Devonian) Groups in northern New South Wales. Benson (1913b) and Spry (1954) refer briefly to spilites in the Woolomin Group. In the area studied by Benson they are usually deformed, and in general very little is known of them. It is evident, however, from their association with greywackes, breccias and jaspers that the Woolomin spilites were geosynclinal and, presumably, submarine. The situation in the Tamworth Group is clear to the extent that the spilitic rocks in the group are essentially unmeta-morphosed. These latter spilites are known mainly through the work of Benson (1913b, 1915a, 1915b) at Nundle and Tamworth. In the Nundle area, a geosynclinal succession of greywackes, breccias, limestones and argillites or cherts carries a considerable amount of basic igneous material. Radiolarian remains have been found in the cherts both here and at Tamworth. David (1896) considered a shallow water origin likely for the cherts at Tamworth. Sill-like bodies of albite dolerite, some of them hundreds of feet thick, occur particularly in the lower part of the succession at Nundle. This succession is of the order of 6,000 feet thick. As Benson (1915a) remarked, the albite dolerites are distinguished from spilites only on the basis of differences in grain size

and a complete gradation exists between the two. Locally, a spilite unit invades a dolerite; in another place the opposite relation holds. Both dolerites and spilites clearly belong to the same period of igneous action. Despite the thickness of the dolerite sills they must have been intruded under very little cover. Pillow structures are common in the spilites and seem to be more abundant near the tops of individual "flows". I use the word "flows" in parenthesis because many of these spilite units were, as Benson realized, partly intrusive in unconsolidated, wet sediments. The term "ploughing" used by Geijer (1916) with reference to lava action at Kiruna seems most appropriate in this connection. Benson (1915*b*) mentions subordinate keratophyres as occurring with the spilites at Nundle, but points out that the more acid rocks are commoner to the north. I must admit that, so far, I have not found any keratophyres in the spilite succession at Nundle; light coloured pegmatitic veins and patches are, however, present in the albite dolerites. Great pods of serpentinite appear beneath the dolerites and spilites, but it is now generally recognized that this ultrabasic material was introduced during Carboniferous or Permian times. An association of spilites with greywackes, breccias and cherts was recognized at Bundook, some 60 miles south-east of Nundle, by Benson (1916). Voisey (1939) correlates this occurrence with the Tamworth Group at Tamworth and Nundle.

The Devonian spilite from the Silverwood–Lucky Valley area in Queensland (Richards and Bryan, 1924) represents the only example of this rock, so far as I know, in Queensland. The associated sediments are tuffs (? greywackes) and radiolarian cherts, and the spilite, which contains an intermediate plagioclase, occurs with other effusive types described as andesites. In fact, Richards and Bryan suggest andesite as an alternative name for the rock in question.

Some years ago, Vuagnat (1949*a*) pointed out that there exist in the Alpine region at least two groups of rocks possessing spilitic characters. One of these, the ophiolitic spilites, we have noted already. The other group mentioned by Vuagnat includes the spilites of Glarus and those of Pelvoux and the Aar massif. In these latter cases the spilites are associated typically with detrital sediments of epicontinental or even continental type. Amstutz (1954) has recently described such a group of spilites from the Verrucano (Permian) of the Helvetic Zone in the Alps. These rocks were first called spilites about the middle of the last century; later they were known as melaphyres, as weiselbergites, as navites, and even as olivine tholeiites. As some of these names were bestowed in the belief that the rocks contained calcic feldspar, Amstutz prefers the name spilite; certainly they are akin both chemically and mineralogically to spilites from other environments. In the Verrucano, spilites are associated with red conglomerates, sandstones and red clay-slates, indicating perhaps an arid environment. Pillow structures have not been found and some of the spilites may have been sub-aerial. Keratophyres and quartz porphyries (? = rhyolite) also occur here and, in general, the more siliceous rocks are more abundant in the younger horizons. These effusive rocks appear to represent the last manifestations of Hercynian igneous activity (Cadisch, 1953). Vuagnat (1947), in a short note, has emphasized the spilitic character of the so-called melaphyres of Pelvoux (Termier, 1898) which include the original *variolites du Drac*. These spilites, like those of similar age (Upper Triassic–Lower Lias) from the Belledonne massif (den Tex, 1950), are apparently epicontinental.

The suite of spilitic greenstones from the Pre-Cambrian Dalformation of S.W. Sweden, studied by van Overeem (1948), offers another example of epicontinental spilites. These rocks are effusive or "subeffusive", and although pillow structures have not been found the lavas seem to be mainly submarine. One flow has a scoriaceous top and shows ropy lava features; it may have been subaerial. Some of the spilites show signs of autobrecciation and the associated sandstones are tuffaceous; other sediments in the succession include arkoses, slates and marls. Keratophyres or other more acid types of effusives are quite lacking in this occurrence. Epicontinental spilites in Karelia have already been noted.

An interesting case of spilites in an epicontinental environment is provided by Norin (1937). In the eastern T'ien Shan (western China) late Pre-Cambrian arkosic quartzites, slates, tuffs and lavas lap over a highly metamorphosed Archaean basement. Acid lavas (keratophyres and quartz porphyries) and tuffs inaugurated an eruptive cycle. Spilitic lavas, regarded as submarine but lacking in pillow structures, accumulated during a later phase which was succeeded by a glaciation. Higher in the sequence, in Lower Palaeozoic beds, a spilite unit occurs with calcareous sediments and with cherts (phtanites), some of which may be radiolarian and others contain material like anthracite. Norin comments on the association of cherts and spilites as a common one; but this particular occurrence is somewhat unusual.

The Lower Permian (Rotliegende) of Lower Silesia includes a succession of volcanic and "subvolcanic" rocks interlayered with shales and sandstones. Rocks called melaphyres, but now interpreted as spilites by Dziedzicowa (1958), with quartz dolerites, quartz porphyries and pyroclastic material represent contemporaneous igneous activity—activity which Kozlowski (1958) regards as the final eruptive manifestations in the Variscan cycle. Dziedzicowa claims that the spilites, which are distinctly more potassic than the majority of rocks called spilites, are not submarine; they may have been subaerial or extruded into local basins. Pillow structures are apparently absent.

The toadstones of Derbyshire, regarded as spilites by Brongniart and called potash spilites by Sargent (1917), represent contemporaneous igneous activity during Visean times. These rocks occur as flows and intrusive bodies with pyroclastic types ranging from agglomerates to fine tuffs within the Carboniferous Limestone. The association is distinctly lacking in normal detrital sediments, but in view of its close connection in time and place with the deposition of limestones the vulcanism was almost certainly submarine and in a shallow water environment. Some of the limestones near the lavas appear to be silicified. Within the igneous units there is considerable variation in the nature of the feldspar. Sargent records both labradorite/andesine and albite/oligoclase; orthoclase is inferred from the chemical composition of the rocks. He considered the rocks had affinities both to the spilites of Dewey and Flett and to mugearites. Lavas in the Carboniferous limestone of the Bristol area were regarded as similar to the toadstones. Pillow structures are absent from Sargent's rocks, though pillow lavas are recorded elsewhere in the Pennine region (Fearnsides and Templeman, 1932). Sargent's diagnosis of these rocks as potash spilites has not met with general recognition and they are sometimes regarded as altered olivine basalts. More recently, Tomkeieff (1941) has described a potash spilite from an intrusive body in the Lower Carboniferous Kelso traps of Roxburghshire. The traps were mainly subaerial flows and belong to the late Palaeozoic alkaline (sodic) province of the south of Scotland. In this occurrence fresh olivine basalt of the Dunsapie type grades into metabasalt with progressive replacement of calcic feldspars by albite and the ferromagnesian minerals by chlorite. The rock described as potash spilite occurs as a small mass within the metabasalt with a rapid but continuous transition between the two types. Veins rich in carbonates and/or quartz are numerous and penetrate the complex.

Spilitic andesites, amygdaloidal spilites and spilitic olivine diabases have invaded Cambrian shales and sandstones, locally overlain by Lower Silurian beds, near Malvern in Worcestershire (Blyth, 1935). Albitization of the shales has occurred on a restricted scale. There are no local signs of effusive action, but as the rocks are post-Cambrian and pre-Lower Silurian, Blyth links them with the Ordovician spilites in Wales. Tomkeieff and Marshall (1940) have recognized spilites (sometimes variolitic) with olivine dolerites, olivine basalts and trachybasalts as Tertiary dyke rocks invading lower Palaeozoic grits and slates in Co. Down, Northern Ireland. These dykes are presumably related to the Tertiary plateau basaltic extrusions in Northern Ireland, though I am not aware of any record of spilites in the flows; mugearite, however, is recorded (Walker, 1960).

An intrusive spilitic body in New Mexico apparently unrelated to surface vulcanism has recently been described by Duschatko and Poldervaart (1955). This intrusion, one

of a number in the area, is a partly discordant sheet 100 to 150 feet thick and invades
Permian siltstones and gypsum, the siltstones being locally converted to adinoles.
Rock types ranging from spilitic basalts and spilitic dolerites to albitites occur in the
intrusion; intrusion breccias appear locally. Duschatko and Poldervaart consider that
the depth of cover under which this body consolidated was probably of the order of
1,500 feet.

TEXTURE AND MINERALOGY OF SPILITES.

We saw earlier that Rosenbusch (1901) distinguished between granular diabases
and fine-grained diabases or spilites. This notion of spilites as fine-grained rocks harks
back to the original definition. Dewey and Flett likewise separated their spilites from
the associated coarser-grained albite diabases. As the albite diabases (or dolerites)
are usually similar to the fine spilites in mineralogy and chemical composition some
authors have regarded both groups as spilites. This is the view taken by most Swiss
students of the ophiolite associations. Benson (1915b) states that at Nundle, "the
distinction between the dolerites and spilites is one of grain size only, and is a most
indefinite one". Intersertal and ophitic fabrics are recorded by Benson in the Nundle
dolerites, while the associated fine-grained spilites are commonly somewhat glomero-
porphyritic with groups of feldspar and pyroxene units, the pyroxene often attached
to the ends of feldspar laths in a sub-ophitic fashion. Terms such as ophitic, sub-
ophitic and intergranular should not be used, however, for the fabrics of many spilitic
rocks without some explanation. As the term ophitic, for example, has definite mineral
connotations, namely, a certain relation between feldspar and pyroxene, it cannot be
used without qualification for those spilites which carry no fresh pyroxene but have
only pseudomorphs of, say, chlorite after ophitic pyroxene. Vuagnat (1946) has
given attention to this matter and decided to use the term intersertal for his Alpine
spilites. In applying this name Vuagnat wanted to have a textural term which could be
used in a general sense independent of the nature and size of the units involved. His
use of intersertal accords with the original definition (Zirkel, 1870), which is general
enough to include ophitic, diabasic (doleritic) and even hyalopilitic textures. More
recently, van Overeem (1948) has recognized varieties of intersertal textures in the
spilites of the Dalformation in S.W. Sweden. The thicker spilite units studied by
van Overeem contain "pegmatitic facies" which also display intersertal textures, the
spaces between the feldspar laths being filled with hornblende or aggregates of epidote,
chlorite and ore minerals.

Variolitic textures are common in many spilites and, in addition to radiating
feldspar groups, arborescent or plumose growths of femic minerals have been noted
(e.g., Taliaferro, 1943; Vuagnat, 1949a; Reinhard and Wenk, 1951; Scott, 1951; Battey,
1956). Scott (1951) illustrates examples of intergrowths of augite and albite in spilites
from King Island, Tasmania, while van Overeem (1948) has found irregular inter-
growths of albite and hornblende. Fluidal arrangements of feldspar microlites are
sometimes sufficiently well developed to merit the term trachytic (Lehmann, 1933;
Reinhard and Wenk, 1951). The larger feldspar microlites in the spilites at Nundle
are commonly bent, and as there are locally no signs of post-consolidational deformation
it may be inferred that the bending is a primary magmatic character. Similar bent
feldspars have been observed in some of the Swiss spilites (Amstutz, 1954) and in
Sweden (van Overeem, 1948).

Amygdules and veins appear in almost all recorded spilites, but unfilled cavities,
on the other hand, seem to be rare. In addition to the concentration of certain phases
in amygdules and veins one often finds minerals such as epidote or chlorites in
irregular or even pseudomorphous patches scattered through the groundmass. Although
the variety of textures observed in spilites may not be great, there is often a good
deal of textural inhomogeneity even on the scale of a thin section. Local variations in
fabric are especially common in the pillowy spilites. The term *spilitische Struktur*

once applied to rocks characterized by the absence or rarity of so-called intratelluric segregations (Loewinson-Lessing, 1901) fortunately has disappeared from use.

In general, we may conclude that the majority of rocks called spilites display textural features analogous to those observed in basalts, dolerites, and perhaps andesites. There are, however, important mineralogical differences between the two groups, and these differences are reflected in such features as colour and specific gravity.

Following Dewey and Flett, most modern petrologists recognize alkaline feldspars as characteristic of the spilitic rocks. Commonly the alkaline feldspar involved is albite (or, less frequently, sodic oligoclase). Considerable variation exists as to the state of this feldspar. Sometimes clear and transparent with few, if any, included mineral grains, the feldspars of spilites are at least equally often patchy, clouded, and in some cases quite choked with inclusions. Where clear and clouded feldspars appear in the same rock it may occasionally be demonstrable that the clear units are outgrowths or overgrowths (e.g., Gilluly, 1935; Nicholls, 1959) or occur in veins or nodules (e.g., van Overeem, 1948). In the fine-grained spilites at Nundle the feldspar is almost always clear with very few inclusions. The nature of the included material in spilitic feldspar varies, and if one is to judge from the literature the significance attached to these inclusions is also variable. Dewey and Flett showed that in their British spilites many of the feldspar individuals are filled with minute grains of chlorite and epidote and suggested that the lime of the epidote was supplied through the replacement of a more calcic feldspar by the present albite host. Inclusions of other lime-bearing minerals have also been observed in the feldspars of spilites; thus, for example, Nicholls (1959) records calcite, prehnite and sphene, while Scott (1951) notes the occurrence of hydrogrossular. The feldspars of the spilitic Kiruna greenstones sometimes carry inclusions of hornblende and scapolite (Sundius, 1915). On the other hand, many spilites from the Alps have feldspars containing chlorites and sometimes micas, but few, if any, inclusions of calcic minerals, certainly few inclusions of epidote-clinozoisite (e.g., Amstutz, 1954). Van Overeem (1948) finds a similar absence of calcic inclusions in the albites of his Swedish rocks; in some cases, chlorite and sericite inclusions are confined to single twin lamellae. Chlorite flecks in the feldspars of some New Zealand spilites are regarded by Battey (1956) as primary inclusions or at least the alteration products of primary inclusions. This accords essentially with the view of Amstutz. The term *"gefüllte Feldspate"* is used by some Swiss petrologists with reference to the feldspars of spilites; it has the great advantage of no genetic connotations.

Data relating to the optical and chemical characteristics of spilitic feldspars are unfortunately scarce. Apart from the analysis (corresponding to $Or_5 Ab_{90} An_5$) given by Sundius (1915) for a feldspar from a Kiruna greenstone I know of no analysed spilite feldspars. Several authors (e.g., Gilluly, 1935) have offered suggestions based on bulk (rock) analyses regarding the potash contents of these feldspars, but specific information is lacking. Especially desirable are data on phases such as the so-called "Na-potassiumfelspar" of van Overeem (1948). At the present time, determinations of the compositions of spilitic feldspars are made exclusively using optical techniques. Most of these feldspars apparently fall in the range An_{0-8} with only a very minor proportion grading into the sodic oligoclase range. Regular compositional zoning is not common, though there are numerous records of albite zones around patchy, inclusion-rich cores. Since about 1930 a great deal of attention has been devoted to the study, structural, optical and chemical, of the plagioclase feldspars. One of the important results of this work has been the demonstration that the plagioclases exist in different optical and structural modifications dependent mainly on their thermal history. Briefly, and with much over-simplification, the situation is that a plagioclase chilled rapidly from a high temperature tends to show a set of optical and structural characters contrasted to those found in a feldspar of the same composition which has been allowed to cool from a melt over a considerable period of time (as, for example, in a plutonic environment). The former modification, common in many rapidly chilled lavas, is known as a high

temperature feldspar, while plutonic and metamorphic plagioclases are usually of low temperature type; transitional varieties are also known.

Van der Kaaden (1951) records low temperature optics in the albites of spilitic material in the Taveyannaz sandstone of the Grisons. Low temperature albite is also characteristic of spilites from North Auckland, New Zealand (Battey, 1956). Nicholls (1959) has found low-albite in spilites from Wales. A check of thin sections of spilitic rocks from eastern Cornwall, from the Lahn area of Germany, and from Russian Karelia (Lake Onega area), in the collections of the University of Sydney, shows a consistent development of low-temperature albite. Over the past few years I have collected several hundred spilitic rocks in the Nundle area of N.S.W. and all of the albites have low-temperature optics (see Figs 1 and 2). It is important to recognize that many of these
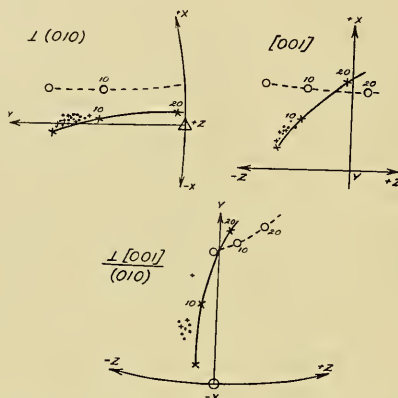

Figure 1.—Optical variation curves of Albite, Carlsbad, and Albite-Carlsbad twins in sodic plagioclases (data from van der Kaaden, 1951). The low-temperature curves are drawn as solid lines, the high-temperatures curves are dashed. Spilitic feldspars from Nundle are represented by spots, feldspars from associated greywackes are marked by crosses.
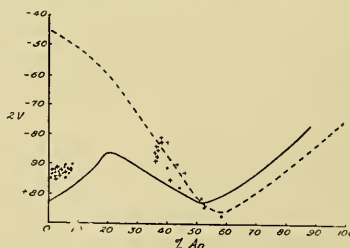

Figure 2.—Chart showing variations in 2V with composition for high- and low-plagioclases (curve from J. R. Smith, *Ann. Rept. Carnegie Inst.*, 1955-56). The high-plagioclase curve is dashed. Spilitic feldspars from Nundle are marked by spots, feldspars from associated greywackes by crosses. Although many andesines and labradorites are plotted, these are quite subordinate to albite in the Nundle rocks.

albites are from rocks which were once partly glassy. However, a couple of once partly glassy rocks, occurring with the spilites at Nundle and texturally indistinguishable from the latter, carry small laths of clear calcic andesine (avge. An_{48}) of high-temperature or transitional type. Reference to Figure 2 will indicate that the albites studied have optic axial angles greater than those expected of low-temperature plagioclases of corresponding composition. Van der Kaaden (1951, p. 29, fig. 10) has found a similar character in his spilitic albites. There may, however, be a complete gradation to "normal" low-temperature values in spilitic albites as both van Overeem (1948) and den Tex (1950) give examples of such albites with lower values of 2V. The albite with 2V of 76° (−) listed by Jaffé (1955) is quite exceptional.

Twinning is common in the albite microlites and phenocrysts of most spilites. At Nundle, twins with (010) as composition plane are particularly common; Albite twins being abundant with Carlsbad and Albite-Carlsbad twins much less frequent but developed in roughly equal proportions. Pericline twins are scarce, and although Acline (Manebach-Ala) and Ala A (Manebach Acline) twins have been measured, these (001) twins are quite rare. Some of the feldspar microlites are untwinned, while many of the small laths exhibit only 2 or 3 lamellae. Phenocrysts (10–15 mm. in length) often carry 3 or more lamellae of varying width; not uncommonly these feldspars show combinations of Albite, Carlsbad and Albite-Carlsbad twins. Both van der Kaaden (1951) and Amstutz (1954) record Albite twins as commonest in their spilites, while van Overeem (1948) notes that Carlsbad twins are especially abundant in some of his albites.* Dziedzicowa (1958) records only Albite twins in the alkaline feldspars of her spilites, though other laws are represented in the calcic feldspars of a group of associated dolerites. Ala-B twins have been recognized by Rittmann (1940) in a spilite from Greenland. In addition to the twin laws mentioned above, van Overeem has recognized Manebach twins, while van der Kaaden lists Baveno twins, Banate 'twins' and Penetration twins, and Amstutz has discovered Roc Tourné twins in Swiss spilites. Although these authors supply some information on the width and frequency of twin lamellae in spilite albites, I know of no systematic statistical studies of these features.

We have noted already Gilluly's suggestion based on bulk composition that some spilitic albite may contain small but varying amounts of potassium. There are cases (potash spilites, poenites, weilburgites), however, in which recognizable potassic feldspars are developed. Small amounts of potassic feldspar have even been observed in "normal" spilites. Thus Eskola (1925) records antiperthitic growths from Karelia. Sargent (1917), the first worker to apply the name spilite to rocks rich in potassium, offered little optical information on his feldspars. A toadstone from Miller's Dale, Derbyshire, in the University of Sydney collection, contains calcic andesine and labradorite with high to transitional optics; a little untwinned orthoclase occurs interstitially. The study on a potash spilite from near Kelso, Scotland (Tomkeieff, 1941), includes optical information on seven phenocrysts. Plagioclases range in composition from about An_{25} to An_{60} and, apart from two ambiguous cases, these feldspars all correspond to low-temperature types. Associated with the plagioclases, Tomkeieff records sanidine, orthoclase and anorthoclase.

Lehmann (1949) claims that his weilburgites (formerly spilites or keratophyric spilites) in the Lahn Trough, Hesse, Germany, carry orthoclase, albite, anorthoclase and "Kalinatronfeldspat". The distribution of these minerals is variable, in some weilburgites albite predominates, others have chiefly K-feldspar, while yet others contain both sodic and potassic feldspars. According to Turner and Verhoogen (1951, p. 203), the poenites of Timor contain adularia, but, unfortunately, I have not seen the original description of these rocks (de Roever, 1942). One would certainly expect to find adularia in potash spilites by analogy with the low-temperature albites of sodic spilites.

In the fine-grained spilites at Nundle, recognizable quartz is rare except in veins where it may occur with clear, anhedral and sometimes untwinned grains of albite. The originally glassy patches may have carried excess SiO_2, though free quartz has not been observed among the products of devitrification. The coarse-grained rocks (albite dolerites of Benson (1915a)) on the other hand often contain up to 5% of granular quartz interstitial to albite laths. Quartz is, in fact, present in minor amounts in a great many spilitic rocks described in the literature. Flett (1911), Vuagnat (1949b) and Scott (1951a), for example, record disseminated quartz as a minor constituent of spilites. It occurs more often as interstitial patches (e.g., den Tex, 1950; Nicholls, 1959) in the groundmass, or, in rocks with doleritic fabrics (cf. the albite dolerites at Nundle), as units interstitial to the feldspar laths (Eskola, 1925). Most frequently, however,

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* The optical distinction between Albite and Carlsbad twins in albitic feldspars may be almost impossible unless, say, a second cleavage (001) is apparent.

quartz is recorded as vein or cavity fillings (e.g., Dewey and Flett, 1911; Eskola, 1925; Gilluly, 1935; Nicholls, 1959). Some of the quartz studied by Nicholls may have inverted from the high form.

Micropegmatitic intergrowths of quartz and potash feldspar occur in the "sodium potassium spilites" at Swierki, Lower Silesia (Dziedzicowa, 1958). Benson (1915a) claims that interstitial micropegmatitic intergrowths of quartz and feldspar sometimes occur in the dolerites at Nundle. These latter intergrowths must involve quartz and albite, as Benson states that potassic feldspar is absent from the dolerites and spilites. Minute quartz-albite intergrowths are reported by Duschatko and Poldervaart (1955) in an albitite associated with spilitic rocks in New Mexico. From the common occurrence of quartz in cavities and veins it is apparent that this mineral is often of late-formation in spilitic rocks. In addition, some authors (e.g., Amstutz, 1954) also mention quartz as one of the alteration products of primary minerals such as pyroxene. Chalcedony (Wells, 1925) and opal (Reinhard and Wenk, 1951) have also been found in spilites.

I know of no examples of spilites containing fresh olivine, though pseudomorphous aggregates after olivine have been frequently observed in spilites from various parts of the world. Considerable variety apparently exists as to the material replacing olivine. Sundius (1915) notes hornblende aggregates after olivine. Van Overeem (1948) records pseudomorphs of "serpentine and actinolite" replacing olivine crystals, the cleavages of which are now outlined by granules of ore minerals. Pseudomorphs identified as "chlorite" are mentioned by Gilluly (1935), Vuagnat (1946), Scott (1951a) and Jaffé (1955). In a spilitic pillow diabase from Oberhalbstein (Grisons), Vuagnat (1948) has noted olivines replaced by a green substance, with optical characters "intermediate between those of bowlingite and those of iddingsite". The Swiss spilites studied by Amstutz (1954) contain pseudomorphs after olivine and augite, and as alteration products he lists (p. 72): haematite, limonite, chlorite, serpentine, iddingsite, bowlingite, calcite, quartz, and perhaps also sphene and leucoxene. Calcite pseudomorphs after olivine are mentioned by Dziedzicowa (1958), while Scott (1951a) gives an example of olivine replaced by hydrogrossular in a picritic rock. In many of these replacements it is apparent that considerable migration of material must have taken place. Traces of original olivine have not been seen in spilites from North Auckland (Battey, 1956), Tayvallich (Flett, 1911; Vuagnat, 1949b) and Builth (Nicholls, 1959). Benson (1915a) does not mention any signs of olivine in the spilites at Nundle; I have found none in these rocks.

Fresh pyroxene is an important constituent of some spilites such as those from Nundle (Benson, 1915a), Karelia (Eskola, 1925), Tasmania (Scott, 1951a) and New Zealand (Battey, 1956). In New South Wales unaltered pyroxene has also been observed in spilites at Bundook and Woodstock. There are, however, many spilitic rocks which carry partly or completely replaced pyroxene grains (e.g., Sundius, 1915; van der Waals, 1946; Amstutz, 1954; Backlund, 1932; Dziedzicowa, 1958; Nicholls, 1959), while some others such as those at Tayvallich (Flett, 1911; Vuagnat, 1949b), some of the ophiolite spilites of the Alps (Vuagnat, 1946, 1948; Jaffé, 1955) and probably the spilites of the Dalformation, Sweden (van Overeem, 1948), show no signs of having once contained pyroxene.

Despite numerous records of spilites containing pyroxenes, little information as to the optical and chemical properties of these minerals is available. The analysis given by Scott (1954) of a pyroxene from a spilitic lava at Queenstown, Tasmania, appears to be unique. Pyroxenes from spilites at Nundle are being studied at present, though only one incomplete analysis is now available. Both of these analysed pyroxenes are alumina-rich and moderately titaniferous types. The Tasmanian example is regarded as a salite, the Nundle pyroxene, with a little less lime, is a common augite according to the nomenclature of Hess (1941). In Table 1 some optical properties of spilitic pyroxenes are listed. Apart from a few examples from Borneo, these pyroxenes appear to be salites or common augites with apparently ferroaugite represented in the suite from Builth.

Reinhard and Wenk (1951) record pigeonite as occurring occasionally in the spilites of North Borneo. According to Kurshakova (1958), pigeonite is found in spilites from the Blyava district of the southern Urals; no optical details are given and the definitive study on this area (Zavaritsky, 1946) is not available in Australia. Some of the albite dolerites of Dinas Head, Cornwall, carry pigeonite (Agrell, 1939), but the few specimens of albite dolerites from south-eastern Cornwall (Saltash area) which I

TABLE 1.
Optical Characters of Pyroxenes from Spilites.

Locality.	Sign.	2V.	$\hat{Z}$ c.	R.I.	Source.
Bundook, N.S.W. ..	+	50° (average)	45° (average)		T.G.V.
Nundle, N.S.W. ..	(+)	42°–48°			Benson (1915a).
	+	49° (average)	46° (average)		T.G.V.
Woodstock, N.S.W.	+	51° ,,	47° ,,		T.G.V.
King Is., Tasmania	+	51°	40°		Scott (1951a).
Queenstown, Tasmania.	+	51°	50°	γ 1·72	Scott (1954) anal.
North Auckland, N.Z.	+	47° (average)	42°–45°	β 1·698	Battey (1956).
Mossburn, N.Z. ..	+	50°	40°		Reed (1950).
Borneo	+	40°–60°	40°–50°		Reinhard and Wenk (1951).
	+	20°–30°			Reinhard and Wenk (1951).
Karelia	+	50°	39°	α 1·697; γ 1·720	Eskola (1925).
	+		40°	α 1·685; γ 1·708	Eskola (1925).
Nowaya Zemlya ..	+	44°	40°		Backlund (1930).
New Mexico ..	+	50°–55°		β 1·680–1·685	Duschatko and Poldervaart (1955).
	+	46°–50°			Duschatko and Poldervaart (1955).
Builth, Wales ..	+	47°–49°		β 1·704–1·708	Nicholls (1959).
	+	46°		β 1·712	Nicholls (1959).
	+	48°		β 1·695	Nicholls (1959).

have examined contain common augite. On the whole, pigeonite appears to be rare in spilitic rocks, the common pyroxenes of which are common augites, salites and ferroaugites. To judge from the colours noted many spilitic pyroxenes are titaniferous. I know of no record of rhombic pyroxenes in these rocks. Grunau (1947) lists aegirine augite in a spilite from Arosa, Switzerland. Soda pyroxenes, however, appear to be exceptional.

Some spilitic rocks carry amphiboles, though considerable diversity exists as to the nature and occurrence of these minerals. Fibrous uralite or tremolite-acintolite may occur as replacements of olivine, pyroxene and hornblende (e.g., Sundius, 1915; van der Waals, 1946; van Overeem, 1948; Vuagnat, 1949a). The albite dolerites at Nundle sometimes have augite partly or even completely replaced by fibrous amphibole; amphibole is rare, however, in the finer spilites. In other cases, blades or nodules of tremolite-actinolite may occur interstitially to feldspar, scattered through the groundmass, or even as cavity fillings. Smulikowski (1957) records a rare example in which riebeckite has formed at the expense of olivine and augite. Occasionally, brown or green hornblende is noted (Benson, 1915a; Sundius, 1915; Carstens, 1924; Eskola, 1925; Gilluly, 1935; van Overeem, 1948, p. 51; Lehmann, 1949; Jaffé, 1955). Albite-hornblende rocks (intrusive spilites) occur in the northern part of the Karelian region studied by Eskola (1925). Eskola has described one analysed amphibole from these intrusive spilites. The sample is moderately aluminous, but is chiefly notable for refractive indices lower than those found in amphiboles with comparable Mg:Fe. Eskola suggests that amphiboles of the type analysed may be common in these rocks. Väyrynen (1928) offers a similar example in a spilitic greenstone from Kainuu, Finland. Amphiboles do not appear to be common in the spilites of the Alpine region, and where seen in these rocks

amphibole is often partly replaced by chlorite (e.g., Jaffé, 1955).   Nicholls (1959) illustrates a chlorite-calcite group probably pseudomorphing hornblende in the Builth spilites.   In the spilites of the Dalformation hornblende is commonly replaced by chlorite or biotite (van Overeem, 1948).   Battey (1956) observed that amphibole becomes common in the North Auckland spilites only when these rocks are found within the aureole of a later intrusion.

Micas occur rarely and then only in subordinate amounts in most spilites.   The occurrence of biotite after hornblende in the Dalformation has just been noted; van Overeem has also found green biotite included in feldspar.   Biotite is similarly associated with amphibole and albite at Kiruna (Sundius, 1915).   Some of the spilites in the Dalformation have been subjected to dynamometamorphism, and these types contain green biotite and actinolite, though van Overeem (1948, p. 71) considers that the biotite is original.   Flett (1911) observed a bright green strongly birefringent biotite, associated with quartz and carbonate filling cavities in the spilites at Tayvallich, while Vuagnat (1949b) records green biotite and a golden-brown, rather weakly birefringent "biotite" from spilitic pillow lavas in the same area.   Vuagnat suggests that a colourless mica noted in the marginal zone of one of these pillows is paragonite. Paragonite may also occur in spilitic rocks in New Brunswick (Flaherty, 1934). "Sericite" mica is often reported as an alteration product of feldspars.

Next to the alkaline feldspars members of the chlorite group are perhaps the commonest and most characteristic minerals in spilites.   In many cases, such as the Alpine spilites and the so-called weilburgites, chlorites may be the chief mafic minerals present.   Even in those spilites which contain unaltered pyroxene, chlorite minerals are usually abundant.   As an example, the North Auckland spilites (Battey, 1956) contain bright green chlorite filling "angular intersertal areas, in little rounded pools, in fine veinlets . . . and in amygdules".   Chlorite occurs similarly in the spilites at Nundle.   On the other hand, there are many records of chlorite minerals replacing and pseudo-morphing olivine, pyroxene, or hornblende.   Included patches of chlorite in albite units have been variously regarded as normal inclusions or as due to partial replacements. Originally glassy spilites often contain chlorite-rich aggregates produced in the devitrification.   Glassy fragmental rocks associated with spilites also frequently show this replacement by chlorites (e.g., Hentschel, 1953).   Within a single rock, chlorite minerals may occur as both direct replacement products and as cavity fillings.   Apart from minerals grouped as "serpentine" (and mainly replacing olivine) there appears to be a great variety of chlorites in the spilitic rocks, although many authors simply note the presence of "chlorite".   Types recorded include: pennine (Taliaferro, 1943; Scott, 1951a; den Tex, 1950; Reed, 1950; Thomas and Thomas, 1956; Duschatko and Poldervaart, 1955), delessite (Eskola, 1925; Reinhard and Wenk, 1951; Thomas and Thomas, 1956), ripidolite (Vuagnat, 1949a), clinochlore (Duschatko and Poldervaart, 1955), diabantite (Thomas and Thomas, 1956), brunsvigite (Battey, 1956), aphrosiderite (= thuringite of Hey, 1954) (Holzner, 1938).   Battey has analysed an intersertal brunsvigite from a North Auckland spilite; this with the two analyses of chlorites from German spilites which he quotes apparently completes the list of analysed spilitic chlorites.   A few chlorites have been checked by X-ray powder methods (e.g., the pennine of Scott (1951a) and the ripidolite of Vuagnat (1949a)), but the majority have been identified by optical examination.   Nicholls (1959) quotes compositions of chlorite (apparently mainly brunsvigite and diabantite) from amygdules in the Builth spilites. These identifications are based on optical characters related to the chart given by Hey (1954).   An immediate difficulty in this method is that according to Hey variations in the oxidation state of iron in chlorites lead to variations in refractive indices and birefringence.   As some spilitic chlorites are distinctly oxidized (e.g., the "aphrosiderite" of Holzner) a certain degree of doubt must be attached to determinations of composition based on optical characters.   Nicholls was aware of this difficulty, but all his chlorites are given formulae as ferric iron-free types.   It would appear that the range of

composition in these amygdule chlorites from Builth is not great. Lehmann (1949) claims that the weilburgites of Lahn carry both orthochlorites and leptochlorites, the latter confined to small cracks and amygdules. Unfortunately, insufficient data are supplied to enable one to establish differences between these types. To conclude, on the basis of scrappy information, the common chlorites of spilitic rocks fall within the ranges $Si_{2.5}.Al_{1.5}$ to $Si_{3.5}.Al_{0.5}$ (for a formula with 18 O.OH), total Fe/Fe+Mg values from nearly zero to nearly unity, and Fe_2O_3 up to at least 12·5% (wt.). Of doubtful status is the "celadonite chlorite" in the spilites of Mossburn, N.Z. (Reed, 1950).

Minerals of the epidote-clinozoisite group are commonly reported in spilites, though in some cases these minerals are little more than accessories. The ferriferous epidote, pistacite, appears to be the commonest representative of the group in spilites, if one may judge from the colours and birefringences recorded. A possibly manganian epidote is reported by van Overeem as occurring with nodules in spilites; many of these nodules are rich in pistacite. In the spilites at Nundle, epidote is extremely variable in its distribution. Some of the pillow lavas contain a fine greenish material which is almost pure epidote in the spaces between the pillows. Epidote also occurs at Nundle as a vein and vesicle filling and as disseminated grains sometimes included in feldspar laths but more often scattered through the groundmass. Flett (1911) mentions epidosites associated with spilitic pillow lavas. Although epidote fillings between pillows appear to be somewhat unusual in other spilites there are many descriptions of accessory granular epidote occurring as inclusions (or alteration products) or as groundmass constituents (Dewey and Flett, 1911; Amstutz, 1954; Eskola, 1925; van Overeem, 1948). Epidote minerals as vesicle and vein fillings are also commonly reported. Van der Waals (1946) records zoisite, clinozoisite and epidote (presumably iron-rich) in the spilites of south-east Liguria. In Karelia, some albite-amphibole-epidote (pistacite) rocks, mostly lacking in chlorites, are regarded as spilitic by Eskola (1925), mainly on account of their high soda content. However, as "the soda percentage apparently decreases as the quantity of epidote increases", the epidote-rich members are distinguished as "non-spilitic" (Eskola, 1925).

The epidote-like mineral pumpellyite has been recorded in many spilites (Reed, 1950, 1957; Battey, 1956; Nicholls, 1959; de Roever, 1947; Coombs, 1953; Reinhard and Wenk, 1951; Bloxam, 1958). The mineral usually occurs in vesicles, or veins, in aggregates in the groundmass or as inclusions or patches in feldspar crystals. Coombs et al. (1959) mention pumpellyite with or without prehnite taking the place of epidote in some New Zealand spilites. Pumpellyite fills vesicles in spilites from Bundock, N.S.W., but has not, as yet, been definitely identified in similar rocks at Nundle.

Although magnetite is reported in some cases (Sundius, 1915; Benson, 1915a (magnetitic spilite, p. 132); Flaherty, 1934; Blyth, 1935; Pichamuthu, 1938; Taliaferro, 1943; van Overeem, 1948; Lehmann, 1949; Scott, 1951), it is apparently less common than haematite or ilmenite. Examples of haematitic spilites are reported from many localities (Flaherty, 1934; Vuagnat, 1946, 1948, 1949a, 1949b; van Overeem, 1948; Park, 1946; Lehmann, 1949; den Tex, 1950; Amstutz, 1954; Jaffé, 1955; Dziedzicowa, 1958; Nicholls, 1959). In one case at least (Flaherty, 1934) the haematite appears to be pseudomorphing pyroxene crystals and not magnetite or some other iron ore. Both den Tex (1950) and Amstutz (1954) record limonite. Perhaps the most frequently recorded ore mineral is ilmenite, and identification in this case is usually facilitated by extensive alteration to so-called leucoxene. Flett (1911), Benson (1915a), Sundius (1915), Wells (1925), Eskola (1925), Blyth (1935), Grunau (1947), van Overeem (1948), Lehmann (1949), den Tex (1950), Reed (1950), Jaffé (1955) and Thomas and Thomas (1956) all offer examples of ilmenite in spilites, while other cases are known of leucoxene completely replacing ilmenite. In fact, the list could be lengthened considerably if recorded cases of leucoxene were added. The leucoxene is usually regarded as a variety of sphene, but in many spilites rich in ilmenite/leucoxene separate grains of recognizable sphene are commonly distributed through the groundmass.

According to Amstutz (1954), Lehmann (1949), Kurshakova (1958) and possibly Battey (1956), titanomagnetite also occurs in spilites. Duschatko and Poldervaart (1955) record sphene occasionally replaced by rutile, a mineral also noted as a rare accessory by Lehmann (1949) and Dziedzicowa (1958). Anatase has been identified by X-ray methods in a spilite from the French Alps (den Tex, 1950).

Some authors (e.g., Tomkeieff, 1941) consider that carbonate minerals are present in all rocks called spilites. There are, however, on record many analyses of rocks given this name which contain no carbonate material (see Table 2). The carbonate minerals often have a highly variable occurrence. They are quite lacking in parts of some spilitic bodies at Nundle. In general, carbonates are found in spilites as replacements (e.g., to olivine or pyroxene), as vein or cavity fillings, or as grains or aggregates of grains arranged interstitially. Despite the analysed examples noted above, it must be pointed out that the majority of spilitic rocks contain carbonates and often in quite high proportions. As an extreme case we may refer to a "spilite albito-calcitique" with 70% modal calcite (Jaffé, 1955). The carbonate in spilites is usually identified as calcite, though this should be regarded often as a "sack name". Flett (1915), Sundius (1915) and Thomas and Thomas (1956) mention ferriferous carbonates (? ankerite or siderite). Both dolomite and calcite are supposed to occur in rocks called spilites by Perrin and Roubault (1941). Reinhard and Wenk (1951) record rare aragonite in addition to the much commoner calcite in the spilites of North Borneo. Manganese-bearing carbonates are associated with the spilites described by Park (1946).

Duschatko and Poldervaart (1955) observed barite associated with prehnite, zeolites and calcite in spilite from New Mexico. Barite is apparently a very rare accessory in such rocks, and the only other record I have is that in Blyth (1935). Prehnite and zeolites are rather more common. Geijer (1916) remarked on the lack of zeolites in spilites, but since 1916 a number of examples of zeolite-bearing spilitic rocks have been described. Most of the recorded zeolites are calcic types. Laumontite is abundant in the spilites of the Olympic Peninsula, Washington, and according to Park (1946) is of late formation. The laumontite is associated with minor analcite and other unidentified zeolites. Possible pseudomorphs after analcite are mentioned by Carstens (1924). Chabazite (?) occurs in one spilite from Mossburn, N.Z. (Reed, 1951). The commonest zeolite in the rocks described by Duschatko and Poldervaart is thomsonite. Zeolites are also recorded by Blyth (1935) and Reinhard and Wenk (1951). In most of these cases the zeolites occupy vesicles and veins. Inclusions of prehnite in feldspar are mentioned by van der Waals (1946), Duschatko and Poldervaart (1955) and Nicholls (1959), though prehnite is not restricted to this type of occurrence—Scott (1951a) has observed prehnite as a vesicle filling; in brecciated spilites at Nundle I have seen veins of prehnite serving essentially as a cement.

The mineral babingtonite sometimes occurs with prehnite in veins in the spilites of the North Auckland region (Battey, 1956). Babingtonite is also found there in veinlets with quartz and as isolated units in intersertal chlorite. It is apparently a late stage mineral. Another late mineral rarely recorded in spilites is hydrogrossular (Scott, 1951a, 1951b). Like babingtonite, hydrogrossular may occur in veins and cavities, but has also been observed by Scott pseudomorphing olivine and feldspar, and apparently replacing originally glassy material. Iddingsite replacement of olivine is apparently not common in spilites (Scott, 1951a; Amstutz, 1954). We have already noted Vuagnat's (1948) observation of a mineral intermediate in optics between iddingsite and bowlingite replacing olivine. Den Tex (1950) mentions bowlingite and xylotile in a spilite from the Alps, while Thomas and Thomas (1956) have bowlingite pseudomorphing pyroxene in albite diabases near Strumble Head, Pembrokeshire.

Apatite, usually as disseminated small elongate crystals, is a common accessory in spilites (e.g., Flett, 1909, 1911; Benson, 1915a; Sundius, 1915; Carstens, 1924; Blyth, 1935; Grunau, 1947; van Overeem, 1948; Vuagnat, 1949b; Lehmann, 1949; Jaffé, 1955; Duschatko and Poldervaart, 1955; Battey, 1956). Zircon is apparently a very rare accessory. I know of only one record (Duschatko and Poldervaart, 1955).

Benson (1915a) has observed axinite in veins and vesicles in the spilitic rocks at Nundle. In this area axinite is rather irregular in its distribution, though it appears to be commoner towards the top of the sequence. Axinite occurs in veins associated with spilitic rocks in the mineralized area near L. Pertjärvi, Karelia (Eskola, 1925). Some of the Cornish spilites (e.g., Flett, 1909) contain axinite, and occasionally tourmaline as well, but these borosilicate-bearing spilites are apparently found only within the contact aureoles of granitic intrusions. One brecciated spilitic rock from Bundook, N.S.W., contains datolite in patches, the datolite serving as a sort of cement. Rodolico (1933) has recorded another occurrence of this mineral, in the ophiolites of Tuscany. Scapolite is also occasionally encountered in spilites; examples are given by Sundius (1915) and Spry (1954). In the latter case, at any rate, the scapolite reflects the influence of an intrusive granite body. The iron-rich mineral stilpnomelane has been found by Eskola (1925) in veins in the spilitic region of Karelia. Carstens (1924) had earlier reported the same mineral in magnetite-rich layers associated with the spilitic greenstones in the Trondhjem area of Norway. Stilpnomelane also occurs in a rock of uncertain status in the spilite-keratophyre terrain of Lahn (Holzner, 1933). The region studied by Eskola (1925) includes the type locality of the material called shungite, one example of which, containing 98·77% carbon, was taken from a vesicle in a pillow lava. In Karelia, shungite occurs typically in veins and amygdules where it is usually associated with various forms of silica, with carbonates and sometimes with pyrite. More recently, Aleksandrov (1956) has found shungite in spilitic rocks in the Middle Urals. The occurrence is apparently similar to that in Karelia. Perhaps the puzzling carbonaceous material in some of the Builth spilites (Nicholls, 1959) is akin to this shungite.

Some spilitic rocks are associated with ore deposits of economic importance (e.g., Lehmann, 1940; Zavaritsky, 1946; Amstutz, 1958). The spilites of the Olympic Peninsula, Washington (Park, 1946), for example, are associated with manganese deposits. Hausmannite (Mn_3O_4) and manganese silicates occur in some of these spilites and Park records instances of whole pillows being replaced by manganese minerals. Disseminated sulphides are frequently observed in spilites. Pyrite is usually the commonest of these, and examples are offered by Flett (1909, 1911), Benson (1915a), Sundius (1915), Carstens (1924), Wells (1925), Blyth (1935), Pichamuthu (1938), Perrin and Roubault (1941), Lehmann (1949), Reed (1950) and den Tex (1950). Eskola (1925) lists a number of sulphides, including pyrite, pyrrhotite, chalcopyrite, bornite and sphalerite, occurring in veins in spilitic greenstones. Galena is another sulphide occasionally found in spilitic rocks (Lehmann, 1949).

We have seen that a great variety of silicates (many of them hydrous), carbonates, oxides and sulphide minerals may occur in rocks called spilites. From the few modes recorded in the literature it is apparent that there is also a considerable range in the proportions of the major constituents. For example, a so-called spilite from the Urals (Kurshakova, 1958) carries only about 5% of albite, but has over 50% chlorite with the rest of the rock mainly quartz and ore minerals. Duschatko and Poldervaart (1955) list spilitic basalts and dolerites containing up to 76% feldspar; these rocks are associated with albitites carrying up to 95% feldspar. The extremely carbonate-rich spilite (70% calcite, 29% albite, 1% chlorite) described by Jaffé (1955) was mentioned earlier. Amstutz (1954), in his study of spilites and keratophyres in the Swiss Verrucano, limited these names to eruptive rocks with 40–90% albite and 0–50% chlorite with iron ores, mostly hæmatite, and occasional noteworthy amounts of epidote, calcite, and titanium minerals. Within this scheme "spilites are the basic, keratophyres are the acid, albite-rich, members of the series". Clearly other authors interpret the term spilite more generously, at least as far as the mode is concerned. It would seem, however, that the main mineral assemblages found in spilites are relatively few in number. The commonest of these assemblages are: albite-clinopyroxene-chlorite, albite-chlorite, albite-chlorite-epidote, albite-chlorite-epidote-calcite, albite-chlorite-pumpellyite

calcite, albite-calcite, albite-amphibole-epidote, and albite-amphibole-chlorite.   In each of these cases iron ore minerals are usually present.   Magnetite and/or ilmenite are more often found in spilites of the albite-clinopyroxene type, while haematite and completely leucoxenized ilmenite seem to be commoner in spilites lacking in pyroxenes. In a few cases the albite may be joined by potassic feldspars.

CHEMICAL COMPOSITION.

The crude analysis of a Derbyshire toadstone carried out by Withering and communicated to the Royal Society in 1782 by Joseph Priestley is almost certainly the earliest chemical study on a spilitic rock.   Though now of mainly historical interest, Withering's results indicated that the toadstones were akin to basalt, but had a greater carbonate content than the latter.   In 1850, Gueymard published a group of analyses of the *variolite du Drac*.   Although, again, these results are not completely reliable, a number of general features are evident.   The silica content is of the same order as in basalt, the alumina, iron and magnesia contents are variable, but "non-carbonate" lime (where determined) is very low and the alkali content is distinctly high.   Gueymard stated that he had not found potash in his rocks.   The later work by Termier (1898) on these same rocks indicates that potash is present, but always in very small amounts.

I have gathered in Table 2 92 published analyses available to me of rocks actually named spilites.   In each case I have accepted the author's identification and have only

TABLE 2.

	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	36·94	39·20	39·28	39·35	40·42	40·55	42·17	43·13	43·73	43·96	44·89	44·98
Al_2O_3	17·11	18·80	12·14	16·54	18·15	16·65	13·36	23·25	18·09	17·26	15·80	15·84
Fe_2O_3	1·48	8·61	2·80	5·76	7·46	1·13	3·80	1·87	7·74	9·20	1·40	1·26
FeO	5·70	4·99	7·52	6·97	3·53	9·46	1·35	4·81	5·21	2·69	9·10	6·57
MgO	2·55	10·03	3·66	10·00	13·52	5·20	3·11	6·50	7·38	8·84	4·76	5·78
CaO	15·95	9·69	12·82	5·58	5·39	6·06	18·59	5·58	4·77	7·27	5·44	9·66
Na_2O	2·99	1·88	4·56	3·50	2·65	4·76	1·27	3·60	3·02	3·21	5·53	3·00
K_2O	0·76	0·16	0·08	0·48	1·91	0·27	0·64	3·04	1·85	1·67	0·18	0·83
H_2O+	}3·78	4·52	2·77	6·71	4·32	3·89	}4·52	3·76	4·17	3·21	4·94	3·08
H_2O-		0·10	0·19	0·36	0·17	0·27		1·06	0·13	0·15	0·52	0·36
TiO_2	1·02	2·21	3·53	4·27	1·68	2·95	0·62	—	2·74	1·49	4·06	1·87
MnO	1·36	0·00	0·37	0·28	0·17	0·20	0·77	tr.	—	—	0·08	0·13
P_2O_5	—	—	0·57	0·20	tr.	0·73	—	—	—	—	1·10	—
CO_2	9·66	0·00	10·06	0·34	0·42	7·85	10·33	3·50	0·87	1·30	2·80	6·88
Etc.	0·18	—	0·01	—	—	0·17	—	—	—	—	—	—
Total	99·48	100·19	100·36	100·34	99·79	100·14	100·53	100·10	99·70*	100·25	100·60	100·24

	13	14	15	16	17	18	19	20	21	22	23	24
SiO_2	45·11	45·21	45·26	45·42	45·42	45·56	45·86	45·91	45·92	46·4	46·47	47·03
Al_2O_3	14·89	17·82	15·86	15·94	17·26	16·46	14·29	17·35	15·19	20·4	19·27	22·45
Fe_2O_3	6·58	5·28	1·43	1·70	4·19	6·58	3·99	6·52	5·53	}6·9	4·80	}7·00
FeO	3·49	6·08	6·32	6·04	6·09	4·40	8·11	5·29	7·06		4·03	
MgO	5·24	10·20	5·35	5·62	3·70	7·74	6·73	9·24	6·64	3·5	9·27	8·79
CaO	6·27	3·33	9·24	8·82	7·50	3·72	9·51	3·15	6·87	7·7	2·12	2·92
Na_2O	4·13	3·51	3·37	3·37	4·51	3·13	4·15	3·22	6·93		5·53	2·63
K_2O	3·41	1·70	0·91	0·86	1·43	1·72	0·88	2·18	0·30	0·54	0·78	4·55
H_2O+	}5·83	3·70	3·27	3·46	}6·34	3·77	1·61	4·68	}7·75	—	4·99	}3·65
H_2O-		0·25	0·54	0·61		2·38	0·59	0·35		—	0·33	
TiO_2	1·67	—	1·68	2·00	0·87	1·37	1·98	2·29	1·78	0·24	1·54	—
MnO	0·19	—	0·25	0·18	0·14	0·26	0·21	—	—	—	0·08	—
P_2O_5	—	—	—	—	—	0·62	0·26	—	—	—	0·56	—
CO_2	2·72	—	6·34	5·98	2·96	1·25	3·96	0·49	—	5·8	0·14	1·90
Etc.	—	—	—	—	—	0·05	0·03	—	—	1·1	—	—
Total	99·53	97·08*	99·82	100·09	100·41	100·03	101·14*	100·22	100·26	99·51	99·91	100·92

TABLE 2.—*Continued*.

		25	26	27	28	29	30	31	32	33	34	35	36
SiO_2	..	47·37	47·4	47·40	47·45	47·49	47·53	47·56	47·95	48·05	48·22	48·24	48·35
Al_2O_3	..	21·71	15·7	19·19	17·54	17·33	17·58	14·27	15·82	18·49	14·82	17·55	16·82
Fe_2O_3	..	3·76	2·4	1·48	2·04	8·63	2·17	1·63	1·44	3·00	0·56	1·05	2·85
FeO	..	4·65	9·1	8·26	7·44	4·66	8·85	6·80	2·56	5·52	9·25	7·04	10·21
MgO	..	5·57	4·4	3·60	6·72	4·76	5·94	4·90	3·64	3·74	5·58	5·27	4·46
CaO	..	4·59	7·7	11·25	10·96	7·16	9·48	10·95	8·09	4·63	8·81	10·43	9·55
Na_2O	..	5·08	4·0	3·40	3·93	4·35	2·40	4·61	3·23	6·95	4·95	5·58	3·78
K_2O	..	1·98	1·28	1·31	0·00?	1·74	1·08	0·27	5·24	0·90	0·44	0·97	0·42
H_2O^+	..	4·00	4·1	3·32	2·67	1·90	3·26	2·65	1·42	} 7·81	2·54	2·88	2·32
H_2O^-	..	0·04	0·34	0·34	0·23	0·09	0·10	0·42	0·00		0·15	0·17	0·32
TiO_2	..	1·04	3·6	0·29	—	2·22	1·79	2·40	2·58	0·84	2·68	0·70	0·78
MnO	..	0·07	0·20	0·13	—	—	—	0·30	0·03	0·49	0·23	0·12	0·10
$P_2O_5.$	..	0·22	0·88	n.d.	—	—	—	0·19	0·93	—	0·23	0·10	—
CO_2	..	0·00	—	—	0·55	—	0·31	2·95	6·98	—	1·40	0·11	—
Etc	..	—	—	—	—	—	—	0·35	—	—	0·40	—	—
Total	..	100·08	101·1	99·97	99·53	100·33	100·49	100·25	99·91	100·42	100·26	100·21	99·96

		37	38	39	40	41	42	43	44	45	46	47	48
SiO_2	..	48·39	48·49	48·52	48·55	48·58	48·6	48·70	48·89	49·23	49·30	49·68	49·73
Al_2O_3	..	13·43	18·18	19·36	16·94	14·58	16·1	20·14	18·87	14·95	12·89	15·78	15·63
Fe_2O_3	..	9·19	1·28	2·20	1·12	1·89	7·6	1·84	2·55	6·17	3·72	5·63	3·69
FeO	..	4·65	7·40	8·12	2·59	7·65	4·0	6·53	5·77	5·47	3·79	5·45	3·75
MgO	..	4·26	5·59	4·24	7·02	6·36	3·6	4·79	3·84	5·50	3·97	5·31	6·55
CaO	..	12·83	6·12	7·65	9·89	9·80	6·2	6·67	7·56	4·72	10·49	6·48	5·79
Na_2O	..	3·23	3·94	4·42	5·28	4·02	4·5	4·26	4·14	4·69	5·59	5·07	6·85
K_2O	..	0·99	2·02	0·18	1·63	0·43	1·76	1·07	1·06	1·89	2·05	0·43	0·23
H_2O^+	..	} 2·98	3·66	} 3·38	3·88	2·93	2·9	3·67	2·93	3·95	4·07	3·22	3·89
H_2O^-	..		0·82		0·15	0·68	0·22	0·52	0·66	0·29	0·98	0·26	0·24
TiO_2	..	—	1·40	1·00	1·23	1·77	1·94	1·28	2·42	1·60	1·04	2·04	2·05
MnO	..	tr.	0·14	0·20	0·05	0·46	0·34	0·09	—	0·07	n.d.	—	0·19
P_2O_5	..	0·35	0·22	—	0·37	0·19	0·34	0·11	0·39	0·39	—	—	0·24
CO_2	..	—	0·72	0·47	1·03	1·00	1·45	0·39	0·80	0·72	2·82	—	1·42
Etc.	..	—	—	—	—	0·29	—	—	0·10	—	—	—	0·01
Total	..	100·30	99·98	99·74	99·73	100·63	99·6	100·06	99·98	99·64	100·71	99·35	100·26

		49	50	51	52	53	54	55	56	57	58	59	60
SiO_2	..	49·74	49·80	49·96	50·01	50·04	50·05	50·72	50·76	51·06	51·31	51·46	51·47
Al_2O_3	..	14·85	17·94	11·39	15·38	17·44	18·87	15·37	14·57	15·24	12·67	11·58	15·46
Fe_2O_3	..	1·04	2·37	4·50	4·86	4·90	0·73	1·69	4·11	5·69	0·54	6·63	4·73
FeO	..	10·61	6·74	13·61	9·21	8·16	5·73	6·61	10·59	4·82	7·99	10·25	5·11
MgO	..	2·48	4·02	3·31	5·85	9·36	4·45	7·66	2·86	4·03	2·19	2·88	4·08
CaO	..	6·17	9·00	5·24	6·35	tr.	6·09	9·04	7·54	6·99	8·17	5·60	5·59
Na_2O	..	4·52	4·03	4·62	4·77	0·61	4·93	6·04	5·54	5·54	5·21	4·68	6·05
K_2O	..	0·53	0·20	1·33	0·40	0·17	1·67	0·71	1·04	2·34	0·54	1·02	1·09
H_2O^+	..	3·37	3·54	} 3·09	2·60	} 5·41	3·22	0·58	} 0·94	2·57	2·31	} 2·54	3·32
H_2O^-	..	0·05	0·10		0·23		0·63	0·60		0·04	0·04		0·04
TiO_2	..	2·05	1·70	3·13	0·73	0·05	0·94	1·29	1·60	1·45	1·92	3·38	1·77
MnO	..	0·39	—	0·26	0·21	0·09	0·08	0·14	0·09	0·11	0·45	0·32	0·06
P_2O_5	..	0·62	—	0·19	0·09	—	0·25	0·08	0·06	0·85	0·90	0·34	0·88
CO_2	..	3·18	1·28	—	0·13	—	2·21	tr.	—	0·00	6·15	—	0·00
Etc.	..	0·13	—	0·08	—	3·22	—	—	0·06	—	0·47	—	—
Total	..	99·73	100·72	100·71	100·82	99·45*	99·85	100·53	99·76	99·69	100·86	100·68	99·65

c

TABLE 2.—*Continued.*

	61	62	63	64	65	66	67	68	69	70	71	72
SiO_2	51·52	51·62	52·05	52·09	52·14	52·46	52·61	52·84	52·94	53·01	53·15	53·41
Al_2O_3	15·14	19·98	16·58	12·62	18·93	15·33	13·03	17·32	12·81	15·01	14·39	11·58
Fe_2O_3	8·00	7·34	1·31	0·05	7·42	4·09	3·90	3·12	3·76	7·42	1·28	0·97
FeO	2·02	2·32	5·19	9·52	2·00	6·13	8·48	5·29	9·29	0·92	9·33	9·90
MgO	7·22	2·87	4·65	7·54	4·36	4·69	5·10	8·68	3·65	3·55	4·74	2·59
CaO	3·84	5·68	5·67	9·90	3·60	5·98	7·26	0·99	6·22	4·68	7·04	7·81
Na_2O	5·44	3·66	6·42	3·28	5·10	5·62	5·60	5·32	5·25	3·77	4·58	4·90
K_2O	0·18	2·62	0·27	0·21	0·75	0·19	0·42	0·82	0·18	4·01	1·01	0·82
H_2O^+	4·07	—	3·09	1·97	}4·05	}3·81	1·65	4·28	2·33	2·15	2·02	}3·29
H_2O^-	0·70	0·80	0·83	0·20			0·10	0·13	0·21	0·72	0·19	
TiO_2	2·00	—	0·99	1·16	1·08	0·94	0·72	1·19	2·54	1·48	1·50	3·13
MnO	0·22	0·18	0·07	0·20	0·15	0·18	0·19	0·08	0·21	0·06	0·14	0·18
P_2O_5	0·16	—	0·15	1·28	—	—	tr.	0·14	0·36	0·47	0·19	0·36
CO_2	tr.	—	2·70	—	0·23	—	0·05	0·00	0·00	3·37	0·10	1·19
Etc.	—	2·56	—	0·24	—	—	0·08	—	0·16	—	—	0·05
Total	100·51	99·63	99·97	100·26	99·81	99·42*	99·19	100·20	99·91	100·62	99·66	100·18*

	73	74	75	76	77	78	79	80	81	82	83	84
SiO_2	53·59	53·75	53·86	54·04	54·10	54·20	54·87	54·92	55·04	55·34	55·46	55·75
Al_2O_3	14·22	14·53	14·75	15·04	16·45	15·15	14·98	15·07	13·83	14·76	15·30	13·29
Fe_2O_3	2·03	7·95	3·94	7·79	4·04	7·05	1·65	0·16	2·19	8·83	6·06	0·88
FeO	9·66	0·79	5·90	1·53	6·49	1·60	8·89	9·23	7·39	0·41	3·71	8·46
MgO	3·58	2·84	4·17	3·94	3·69	3·05	3·33	7·44	4·78	2·49	3·89	1·80
CaO	6·18	6·11	7·17	4·08	6·16	6·41	4·06	2·06	7·08	5·53	4·24	6·85
Na_2O	5·52	3·84	5·36	3·74	4·97	3·78	5·73	2·98	5·90	3·60	2·58	4·07
K_2O	0·41	3·31	0·46	2·88	1·01	2·57	1·13	0·16	0·36	3·48	1·55	0·37
H_2O^+	1·49	1·41	2·53	2·48	1·01	1·37	2·39	5·65	}0·77	0·83	}5·30	2·95
H_2O^-	0·39	0·73	0·92	1·07	0·16	0·42	0·25	0·16		0·37		0·20
TiO_2	2·76	1·78	0·72	1·51	1·22	1·60	2·02	0·05	1·15	1·55	1·00	1·86
MnO	0·05	tr.	0·14	tr.	0·26	0·03	0·04	0·08	0·20	0·04	—	0·23
P_2O_5	0·34	0·49	0·16	0·59	0·26	0·44	0·47	—	0·08	0·53	—	0·19
CO_2	—	3·38	tr.	1·69	0·75	3·13	—	—	1·28	3·12	—	3·63
Etc.	—	—	0·07	—	—	—	—	3·62	0·01	—	—	0·17
Total	100·22	100·91	100·15	100·38	100·57*	100·80	99·81	101·58*	100·06	100·88	99·09	100·70

	85	86	87	88	89	90	91	92	93	94	95	96	97
SiO_2	55·86	56·13	56·84	57·04	57·66	58·48	62·92	63·58	49·65	46·01	51·22	50·83	45·78
Al_2O_3	15·17	14·71	14·95	13·31	15·90	15·07	14·33	13·42	16·00	15·21	13·66	14·07	14·64
Fe_2O_3	2·54	1·39	7·68	8·05	1·71	2·10	1·28	2·10	3·85	1·35	2·84	2·88	3·16
FeO	6·98	9·05	0·63	1·10	6·80	6·86	7·24	5·67	6·08	8·69	9·20	9·00	8·73
MgO	2·30	4·87	2·26	3·02	3·07	6·32	4·87	1·37	5·10	4·18	4·55	6·34	9·39
CaO	3·39	2·24	6·02	4·25	2·55	0·07	1·88	2·75	6·62	8·64	6·89	10·42	10·74
Na_2O	5·45	4·58	3·39	3·39	5·06	3·55	2·37	4·31	4·29	4·97	4·93	2·23	2·63
K_2O	2·05	2·80	2·68	3·09	2·81	0·49	2·93	2·93	1·28	0·34	0·75	0·82	0·95
H_2O^+	2·53	}1·66	0·99	2·03	1·44	4·57	2·34	1·85	}3·49	2·48	}1·88	0·91	0·76
H_2O^-	1·21		0·25	0·71	0·21	0·23	0·16	0·30		—		—	—
TiO_2	1·60	2·21	1·71	1·51	1·94	0·64	1·21	0·99	1·57	2·21	3·32	2·03	2·63
MnO	0·19	0·16	0·06	tr.	0·01	0·27	0·16	0·14	0·15	0·33	0·25	0·18	0·20
P_2O_5	0·63	0·38	0·58	0·51	0·47	—	0·45	0·35	0·26	0·61	0·29	0·23	0·39
CO_2	tr.	—	2·51	2·16	—	—	0·18	0·03	1·63	4·98	0·94	—	—
Etc.	0·20	—	—	—	—	1·87	0·08	0·10	—	—	—	—	—
Total	100·10*	100·18	100·81	100·17	99·63	100·11*	99·96	99·89	—	—	—	—	—

excluded analyses published before about 1900. Rocks of probable spilitic character, but called diabases, greenstones, uralite porphyrites, traps, etc., are not listed. An analysis of the spilite from Nemingha, N.S.W. (Benson, 1915b), was omitted inadvertently. The average of these 92 spilites is given in column 93, and, to facilitate comparison, I have added Wells' (1923) average spilite (no. 94), Sundius' (1930) average spilite (no. 95), and Nockolds' (1954) average "normal tholeiitic basalt" (no. 96) and average "normal alkali basalt" (no. 97). In the average no. 93, values for TiO_2, MnO and P_2O_5 are doubtless low because these components have not been estimated in all cases; the corresponding values of Al_2O_3 and iron oxides will thus be high. Although CO_2 is not recorded in some analyses the totals suggest that it is not important in most of these cases.

In view of the fact that both Wells and Sundius had pre-conceived notions as to the composition of spilites and hence their averages are quite selective, it is at least intriguing to notice that all three average spilites are not strikingly dissimilar. How-ever, one does not have to look through many of the 92 analysed spilites to realize that an extreme chemical variability is hidden in the average. In fact, silica varies over a range of about 26% (by weight), while the ranges of the other major constituents are roughly as follows: alumina 12%, ferric iron 9%, ferrous iron 13%, magnesia 12%, lime 18%, soda 6%, and potash 5%. The content of CO_2 exceeds 10% by weight in some cases, but in others carbonate material is absent. Of course, I realize that not all of the analysed rocks (1–92) would be accepted as spilites according to the chemical criteria of Wells and Sundius. It must be understood, however, that even within a single spilitic body there may be considerable variations in both mineralogy and composition. In pillowy spilites there is abundant evidence of chemical variations from core to rim and matrix of the pillows. Slavik (1928) and Vuagnat (1949a, b) offer examples in which the margins and matrices relative to the cores are extremely rich in iron, magnesia and water but poor in silica, lime and alkalis. In the "margined sacs" of the Builth spilites Nicholls (1959) finds rims richer in lime and poorer in silica and soda than the cores; the ratio of Na/K is much lower in the rims. The "chert-like" material between pillows of which an analysis is given by Reinhard and Wenk (1951) is certainly not like most cherts—it contains only 33·57% SiO_2, but has 21·49% Al_2O_3 and 20·46% CaO. Lime-rich "cherty" rocks also occurs at the margins of pillows at Nundle. A series of four samples collected over a distance of 6·5 cm. from core (A) to margin/matrix (D) in such a pillow is represented in Table 3. The dark, "fresh-looking" core is similar to the average spilite (93) and not greatly different from Benson's spilite from Nundle (34).

Compared with Nockolds' average basalts the average spilites are notable chiefly for their lower lime and higher alkali, water and carbon dioxide contents. The average spilites (93, 94, 95) also have less magnesia than Nockold's basalts. All of these components show wide variations in their distribution in spilites. The arbitrary limiting of spilite to rocks with normative feldspar containing less than 40% anorthite

Key to Analyses in Table 2.

Amstutz (1954), nos. 23, 25, 68 ; Backlund (1930), no. 91 ; Bartrum (1936), no. 69 ; Battey (1956), nos. 73, 79, 85, 86, 89, 92 ; Benson (1913c), no. 34 ; Blyth (1935), no. 18 ; Duparc and Grosset (1916), no. 83 ; Duschatko and Poldervaart (1955), nos. 40, 45, 57, 60 ; Dziedzicowa (1958), nos. 70, 74, 76, 78, 82, 87, 88 ; Eskola (1925), nos. 51, 59, 72 ; Gardiner and Reynolds (1912), no. 50 ; Gilluly (1935), no. 71 ; Ginzberg (1934), nos. 21, 39 ; Grunau (1947), nos. 4, 48 ; Guppy and Sabine (1956), no. 44 ; Guppy and Thomas (1931), nos. 2, 3, 6, 22, 28, 31, 41, 49, 58 ; Kurshakova (1958), nos. 53, 66, 80, 90 ; Loewinson-Lessing and Diakonova-Savelieva (1933), nos. 1, 7, 13, 17, 33, 65 ; Nicholls (1959), nos. 38, 43, 54, 63 ; Niggli, de Quervain and Winterhalter (1930), no. 47 ; Pellizer (1954), nos. 12, 15, 16 ; Reed (1950), no. 75 ; Reed (1957), nos. 26, 42 ; Reinhard and Wenk (1951), nos. 11, 46, 55, 61 ; Richards and Bryan (1924), no. 77 ; Sargent (1917), nos. 8, 24 ; Scott (1951a), nos. 27, 35, 52, 67 ; Scott (1952), no. 36 ; Sirin (1937), no. 62 ; Slavik (1908), no. 37 ; Slavik (1928), no. 64 ; Sundius (1930), nos. 56, 81 ; Tomkeieff (1941), no. 32 ; Tomkeieff and Marshall (1940), no. 19 ; van Overeem (1948), nos. 5, 9, 10, 14, 20, 29, 30 ; Wells (1925), No. 84.

Average values : average of spilites nos. 1–92, no. 93 ; average spilite of Wells (1923), no. 94 ; average spilite of Sundius (1930), no. 95 ; average tholeiitic basalt of Nockolds (1954), no. 96 ; average alkali basalt of Nockolds (1954), no. 97.

(Note : Totals marked with an asterisk are incorrectly quoted in the original work.)

<div align="center">TABLE 3.</div>

	A.	B.	C.	D.	
SiO_2	50·00	47·76	39·10	34·68	43·7
Al_2O_3	16·69	16·82	16·25	17·52	16·9
Fe_2O_3..	1·97	2·15	3·82	8·47	3·8
FeO	9·20	9·92	14·20	8·56	10·5
MgO	5·04	5·43	7·57	4·52	5·6
CaO	7·22	6·34	8·93	16·00	9·3
Na_2O	3·74	3·43	1·46	0·64	2·5
K_2O	1·10	1·74	1·16	0·55	1·1
H_2O^+	3·25	3·83	4·77	4·39	} 4·2
H_2O^-	0·14	0·19	0·26	0·29	
TiO_2	1·68	1·87	1·97	4·08	2·3
MnO	0·21	0·24	0·28	0·26	0·2
P_2O_5	0·26	0·30	0·26	0·47	0·3
CO_2	0·00	0·00	0·00	0·00	—
	100·50	100·02	100·03	100·43	—
S.G.	2·91	2·94	3·14	3·23	—

Serial samples across a pillow, from spilite, Left-hand Branch Creek, Nundle, N.S.W. Anal.: Avery and Anderson (alkalis redetermined by T.G.V.).

A, dark-grey core.
B, greenish-grey zone.
C, dark-grey zone.
D, greenish margin.
The figures in the last column represent the calculated bulk composition of the pillow, assuming a spherical shape.

(Sundius, 1930) would clearly exclude many parts of spilitic bodies. Gilluly (1935) demonstrated that the 40% limit has no real meaning; he also showed that the normative feldspars of albite diabases have a similar range to those of spilites. Many new data for spilites plotted in Figure 3 (*a*) confirm Gilluly's view on the arbitrary limit. It is
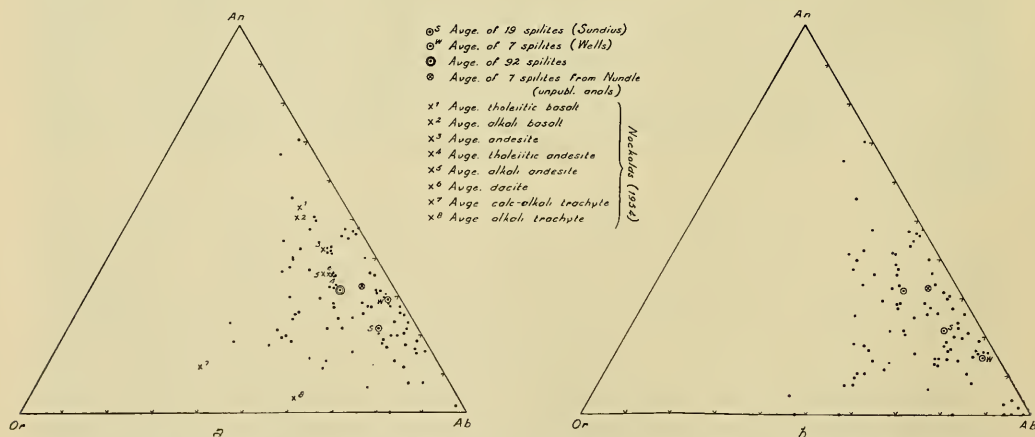
Figure 3.—Diagrams showing variation in normative Or-Ab-An for rocks called spilites (ref. Table 2). Various average compositions have been plotted for comparison. Fig. 3a represents normative feldspars calculated without regard to CO_2 content of the rock; in constructing Fig. 3b normative calcite was allotted before calculating the normative anorthite.

quite clear that spilitic rocks rich in lime are not necessarily rich in CO_2. Even if we make allowance for calcite in the norm a similar wide spread is apparent (Fig. 3, *b*). There is, however, a greater range of normative orthoclase than that shown by Gilluly. Although most students of spilites have claimed that high soda and low potash are characteristic of all spilites, it is evident that potash spilites exist and furthermore that there is a complete chemical gradation between potassic and sodic types. As far

as the normative feldspars are concerned, there is clearly some overlap between normal basalts and spilites. Probably this overlap would be even greater if we could calculate bulk compositions of spilites. As a rough example, the normative feldspar appropriate to the bulk composition given in Table 3 is similar to the normative feldspars of average basalts. In this case, of course, the volume sampled is very small, but the occurrence of lime-rich patches, veins and cavity fillings is common and widespread in many spilitic bodies.

Sundius (1930) claimed that spilites have higher Fe/Mg ratios than basalts, but, as can be seen from Figure 4, there is a distinct similarity between Fe/Mg in
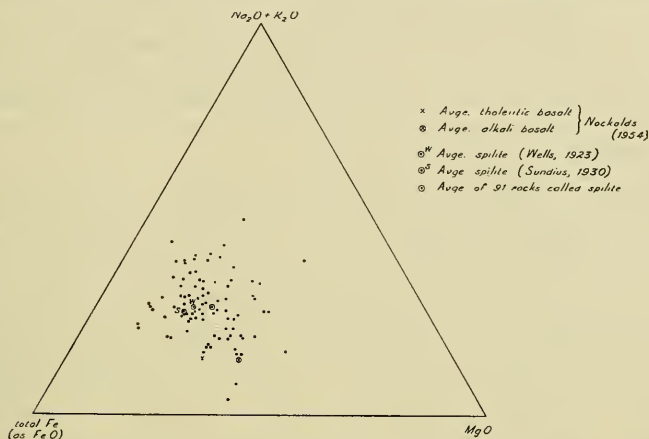
Figure 4.—Diagram showing variation in $Na_2O + K_2O$ – total Fe – MgO in rocks called spilites (ref. Table 2).

tholeiitic basalts and in many rocks called spilites. Low ferric iron content, regarded by Wells (1923) as typical of spilites, is not general. Some groups of spilites, as, for example, those discussed by Dziedzicowa (1958), show consistently high values for ferric iron. The content of titania in the average spilites is not markedly different from that in the average basalts, though high titania was considered a characteristic of spilites by both Wells (1923) and Sundius (1930). In the analysed pillow from Nundle, titania is concentrated in the marginal zone. Perhaps titania, like lime, alkalis and iron and magnesia, is unevenly distributed in many spilites.

It seems to me that the most important chemical differences between basalts and spilites lie in the highly variable distribution of components in the latter. Sampling requires the closest attention in studies on spilites. As Amstutz (1958) has pointed out, most spilite analyses probably represent "fresh" samples, heterogeneous patchy material being ignored. Because of this sampling bias, the apparent differences between the "average" spilites and average basalts may be somewhat illusory. There is almost certainly a weighting of the average spilite in favour of the highly alkaline, lime-poor variants. Only combined water and, sometimes, carbon dioxide seem to be consistently more abundant in spilites than in basalts. One is certainly tempted to regard spilites as more sodic than normal basalts, but in view of the imperfect sampling I can only return a verdict of not proven. Perhaps some rocks called spilites are really hypersodic even in bulk, but I cannot believe that this is true of all rocks so named. It should be noted that the potassic spilites occur typically in epicontinental or continental associations; soda predominates in the alkali-rich parts of geosynclinal spilites.

ORIGIN OF SPILITES.

Controversy on the origin of spilitic rocks commenced even before Brongniart invented the name. We noted in the introduction that Lamanon had regarded the *variolite du Drac* as a volcanic rock, and for this view he was bitterly attacked by

Faujas de Saint Fond, among others. Lamanon later withdrew his paper and recanted. This same Faujas visited the toadstone localities in Derbyshire in 1784, and, recognizing the similarity between toadstones and *variolites du Drac*, concluded that none of these rocks was volcanic (Geikie, 1907). Whitehurst, who regarded the toadstones as volcanic rocks, seems to have been less influenced by Faujas' criticism than was Lamanon, and we find Whitehurst in 1786 stating that the toadstone was "as much a lava as that which flows from Hecla, Vesuvius, or Aetna". Subsequent work has shown the correctness of Whitehurst's view. Brongniart (1827), in his discussion on spilites, paid no attention to the question of genesis, but, as we have seen, it is likely that rocks of quite varied background were grouped together as spilites. Subsequently, the term was restricted more and more to rocks which we would now call igneous. Today, Perrin and Roubault, workers who have made a name for themselves through their advocacy of an extreme transformist view of granite, seem to be alone in regarding spilites (or, at least, one particular spilite) as the product of regional metamorphism acting on beds of quartzose dolomites (Perrin and Roubault, 1941). This view has been strongly attacked by den Tex (1950) and, I think, need not detain us here.

Although the great majority of modern workers agree that spilitic rocks are of igneous derivation and occur chiefly as effusive bodies, there is anything but agreement on the processes by which these rocks acquired their present characters. The theories proposed fall into three very broad groups. Spilites may be magmatic rocks which owe their present characters either to features inherent in the magma (e.g., richness in soda) or to special conditions of crystallization. According to these views the materials of spilites are derived from a magmatic source. Another view would attribute an important place to the influence of sea-water (or water in adjacent sediments) on still-molten magma. In this case some of the components may be derived from an extra-magmatic source. The third group of theories includes those suggestions that spilites are formed through the action of post-magmatic processes on basic igneous rocks. Van Overeem does not recognize rocks of the last group as true spilites, but I think we must consider the implications of post-magmatic action, especially as there is now a growing body of information on the alteration of rocks through diagenesis.

There is considerable evidence that most spilites are adjusted to conditions of low temperature and abundant water. These conditions may obtain in any of several contrasted environments, such as late magmatic (Wilshire, 1959), hydrothermal (Schwartz, 1939), low-grade metamorphic or diagenetic. As far as the origin of spilites is concerned, the important point is whether the adjustment to low temperature conditions is achieved through magmatic or post-magmatic processes. Eskola (1925) and Beskow (1929) were among the first to point out the similarity of spilite mineral assemblages and those of epimetamorphism. What little evidence is available on trace elements in spilites accords with the idea of low temperature adjustment. Both Scott (1951a) and Amstutz (1953) demonstrate higher Sc and Zr in spilites than in normal basalts; the accumulation of these elements suggests a low temperature environment. Despite the richness in Zr in the Swiss spilites zircon has not been recognized, and the only recorded case of zircon in spilites is that given by Duschatko and Poldervaart (1955). However, in this latter case, zircon, though commoner than in normal basalts, is of the same type as "basaltic" zircon.

As albite is a common phase in so many spilites the status of this mineral is especially significant. We have seen that Dewey and Flett regarded most spilitic albite as of replacement origin and, in fact, secondary albite has been regarded by some as essential in rocks called spilites. Turner (1948) claims that "the secondary origin of the albite [in spilites] can hardly be doubted". Many spilitic albites carry numerous inclusions of calcic minerals such as epidote-clinozoisite, and these are commonly considered as indicating an origin through replacement of a more calcic feldspar. In a few cases cores of labradorite or andesine surrounded by albite give clear evidence of original calcic feldspar. There are, however, also numerous examples in which the

feldspars are free from inclusions and occur in environments at least locally deficient in lime. These albites have been interpreted as primary in origin (e.g., van Overeem, 1948; Amstutz, 1954). Clear albite is common in the spilites at Nundle and often occurs in sub-ophitic relation with fresh augite. Benson (1915a) regarded this albite as primary and his opinion has been widely quoted. Scott (1951a, b) and Battey (1956) have found albite crudely intergrown with fresh pyroxene and both consider the albite as primary. Probably no one doubts the primary nature of the clinopyroxene in spilites and it is argued from the sub-ophitic or intergrowth relations that the feldspar crystallized no later than the pyroxene. Certainly some feldspar did crystallize with the augite, but was it albite? Scott (1951a) claims that the albite-pyroxene intergrowths observed in the King Island spilites are eutectic in character analogous with the albite-diopside eutectic recognized by Bowen. This eutectic observed in an anhydrous system by Bowen carries about 97% An; the presence of water in the melt would, as Gilluly (1935) suggested, probably shift the eutectic even closer to the albite end. The intergrowths illustrated by Scott show no such excess of albite. In a later study, Scott (1954) stated that her conclusions on the King Island rocks do not hold generally for the Cambrian spilites of Tasmania, the albite being most commonly of secondary origin. Battey (1956) thinks that the fresh, often plumose augite, with Mg > Fe, in the North Auckland spilites was precipitated metastably "from a liquid in which high water content and consequent free diffusion has permitted the plagioclase to pass down the curve of continuous reaction to produce albite". Albite in the pyroxene-bearing spilites of Karelia is regarded by Eskola (1925) as of secondary origin. Most of the European spilites in which albite is interpreted as primary carry no pyroxene, but often contain considerable amounts of chlorite (van Overeem, 1948; Amstutz, 1954).

The low-temperature optics consistently found in spilitic albites indicate either a low temperature of formation or a complete adjustment during cooling from high temperatures. The latter is not likely in view of the common occurrence of glass in these rocks. However, as high-temperature pure albite is rarely found in any lavas, the low-albite in spilites may not be of itself specially critical. Petrographic experience indicates that low-albite may form directly, for example, in veins and cavities, and also as a replacement to an originally high-temperature more calcic feldspar. Karl (1954) supplies a good example of this latter in which the change was supposedly induced by slight metamorphism. In this process there is no indication of an inversion first to a low-temperature analogue of the primary calcic feldspar; low-albite replaces directly the earlier high feldspar with no observable intermediate steps. Features such as twinning may be inherited from the original feldspar. Donnay (1940), arguing from the French geometrical theory of twinning, on which ease of twinning is related to the obliquity of twin, predicted a systematic variation in the width of albite-twin lamellae with composition in the plagioclase series. Donnay's curve has now been revised by Gay (1956) using more accurate data, but the point remains that albite twinning should be much less frequent and hence the width of the lamellae greater in pure albite than in oligoclase. Obliquity increases again over the range An_{35-100}, but one may expect that for andesines and at least some labradorites the frequency of albite-twins would be greater than in low-albites. If this argument holds there should be systematic differences between the albite-twinning of primary albite and albite-twinning inherited from andesine or labradorite. The problem is essentially a statistical one and so far no one seems to have had the time and patience to tackle it. Again, Emmons (1943) claims that (001) twins are commoner in calcic than in sodic feldspars. If this can be established here is another possibility of distinguishing "inherited" twins from "primary" twins.

Amstutz (1954) has noted that the inclusion-free albites in patches and veins in his spilites are either untwinned or have few broad lamellae. Albites in the spilites at Nundle are often twinned and even some of the microlites of the groundmass may show one or two repeats. Fine albite-twinning in detrital feldspars of greywackes associated

with the Nundle spilites is probably inherited. Most commonly these feldspars are now albite, but two calcite-rich greywackes in which the detrital feldspar is still recognizable as calcic andesine have been studied; the albite-twin frequency seems to be much the same in both albites and andesines. On the whole, I am inclined to regard the albites (except those in veins and cavities) of both spilites and greywackes at Nundle as secondary in origin. One of Benson's arguments for primary albite was that if the albite were secondary there should be signs of alteration in the associated pyroxene. But it is a matter of observation, unexplained as far as I know, that pyroxenes, doubtless metastable, may persist in hydrothermal environments, in sediments affected by diagenesis and in conditions of low-grade metamorphism (e.g., Vallance, 1953).

I do not think that we can be as definite about secondary albite in spilites as Turner (1948), but I must say that the claims of primary albite are not always very compelling. The mere absence of calcic inclusions and local deficiency in lime do not seem convincing criteria of primary origin. In almost every known spilite there are signs of local accumulations of lime. What is the source of this lime? Eskola, Vuoristo and Rankama (1937) have demonstrated experimentally that calcic feldspars are converted to albite, with the release of lime, in the presence of sodium carbonate solutions at moderate temperatures. Is there any comparable experimental support for the notion of primary albite in spilites?

The idea of a parental magma of special chemical character from which is derived a spilitic suite of rocks originated with Dewey and Flett (1911). These authors bestowed on this hypothetical magma the dignity of a place between the Atlantic and Pacific magma-types and claimed for it a characteristic geological occurrence—a spilitic province. Dewey and Flett regarded their spilitic magma as basic, but richer in soda, water and carbon dioxide than normal basaltic magma. Enrichment of late-stage solutions in soda and silica leads to the replacement of early calcic feldspars by albite (cf. Bailey and Grabham, 1909). Wells (1923) adopted this view of a spilitic magma and claimed in support of the idea that spilites were not associated with normal basalts. Not long after, Wells (1925) himself described an example of just such an association, and since that time it has been widely recognized. Sundius (1930) also "adopted" a spilitic magma, but in his view the peculiar composition determined the course of crystallization. Thus, through the inhibition of crystallization of olivine, the available lime is taken up in the ferromagnesian constituents, leaving albite to form as a primary constituent. According to Sundius (1930) there is no need to postulate autolysis and replacement of primary calcic feldspar even though earlier (Sundius, 1915) he had demonstrated the existence of labradorite relicts in the Kiruna spilitic greenstones. Backlund (1930) connected his spilites in Nowaya Zemlya with concentration of alkalis in what he calls an *Ursprungsmagma*, but it is not clear whether he regarded this as spilitic; his other writings suggest that he did not. Nicholls (1959) has recourse to a spilitic magma to account for the Builth spilites, and furthermore claims that metasomatic features are due to the action of related but immiscible liquid phases. There seems to me to be little evidence in support of a spilitic magma distinct from other basic magmas, and the known association of basalts and spilites is especially damaging to Dewey and Flett's claim. However, references are still made occasionally to spilite-keratophyre magma types (e.g., Semenenko, 1955), so the idea is not yet dead. The term spilite suite is still used, but nowadays this does not necessarily imply the existence of a spilitic magma.

The occurrence of adinoles at the margins of some spilitic bodies and the decrease in albitization away from the contacts indicate that these spilites, at any rate, held available soda at some stage during the cooling period. It should be remembered, however, that not all spilites are associated with adinoles. For example, there are no signs of adinoles in the fine sediments at Nundle. Benson (1915a) lists a sediment with 67·87% SiO_2, 1·10% Na_2O and 2·08% K_2O from the contact with a spilite; in some cases potash is even higher, as in this example also from a contact, 67·88% SiO_2, 0·81% Na_2O and 3·46% K_2O (unpubl. anal.).

Although some, perhaps many, spilites carried sodic solutions during the cooling, was this soda derived from the magma or from outside sources? Various answers have been suggested. Eskola (1925), for example, regarded the Karelian spilites as derived from normal calc-alkaline basalt magma and that retention of volatiles coupled with the effects of crystallization differentiation had led to the autolytic alteration of calcic feldspars. Chumakov (1940) seems to hold similar views. The intrusive spilites described by Tomkeieff and Marshall (1940) are supposed to have had their feldspars albitized through the influence of CO_2, the alkalis in these rocks being concentrated through the action of volatiles as carriers. Daly (1933) considered that the quantities of volatiles that could be retained within a magma were insufficient to achieve the mineral changes observed in spilites. According to Daly the magmatic volatiles were augmented by resurgent volatiles from deeper levels.

In recent years a number of European petrologists have outlined a scheme of hydromagmatic crystallization to account for spilites (Burri and Niggli, 1945; Vuagnat, 1946; van Overeem, 1948; Amstutz, 1954, 1958). According to this view spilites are derived from basaltic magma rich in volatiles, chiefly water, and these volatiles are retained during the cooling period. The high volatiles content is supposed to depress the freezing range, with the result that albite and, say, chlorite could crystallize as primary minerals. Niggli (1952) believed that accumulation of volatiles led to the development of spilitic material in the Keweenawan lavas. In this case there can be no doubt of early crystallization of olivine, pyroxene and calcic feldspar. Battey (1956) also appealed to a water-rich magma, but, as we have seen, the main assemblage in his spilites is albite-augite-chlorite, not albite-chlorite. Experimental work on hydrous systems does not offer much support for the hydromagmatic crystallization of spilites. In general, initial crystallization products in synthetic systems containing water appear to be anhydrous, though Yoder and Tilley (1956), in the preliminary work on the system natural tholeiite-water, have shown that abundant water, if retained, will lead to the development of amphibole-bearing assemblages. Crystallization in a water-rich environment might be expected also to lead to high Fe^{+++}/Fe^{++} ratios (cf. Kennedy, 1955). This ratio is extremely variable in spilitic rocks; Wells (1923) even claimed that spilites were notable for low Fe^{+++}/Fe^{++} values. The spilites analysed by Amstutz (1954) do, however, have considerable amounts of ferric iron and some of the Swiss spilites are quite rich in haematite. Hydromagmatic crystallization offers a possible explanation for some spilites, but I cannot believe that it is generally applicable.

Lehmann (1949, 1952a), who distinguishes between spilites (with secondary albite and chlorite) and weilburgites, envisages a process of what he calls "allopegmagenesis" to account for the Lahn weilburgites. He regards albite and chlorite in these rocks as primary, and the rocks themselves are supposed to have originated through the volatiles from an ascending diabasic magma acting on an earlier group of kerato-phyres. These views have been strongly criticized by Hentschel (1952a, b, 1953), who regards weilburgites as spilitic and the albite and chlorite as secondary products.

Some workers have been impressed by the common occurrence of spilites in submarine environments and attribute to sea-water or to water in wet sediments an important chemical role in the development of spilites. Beskow (1929) believed that albitization of calcic feldspar and the conversion of ferromagnesian minerals to chlorite as observed in spilitic rocks in Lapland were due to the action of sea-water heated during the extrusion of basaltic magma. Some of the soda involved in the albitization was thus of marine origin. Park (1946) accepts the idea of sea-water diffusion involving an exchange of Na for Ca. Gilluly (1935) emphasizes with Daly the influence of wet sediments on magma. In the spilites studied by Gilluly albitization of original feldspar seems to have occurred after complete consolidation and may have been related to the action of resurgent water or to the action of albite-rich residual solutions derived from a hypothetical trondhjemitic magma regarded as the source of abundant quartz-keratophyres. Barth (1936) has a rather cryptic reference to spilite as "formed by

stewing of solid rocks in low-temperature liquids". Rittman (1958) and Szádeczky-Kardoss (1958) have both recently appealed to high water-pressures in deep-sea environments as a means of retaining magmatic water. Szádeczky-Kardoss claims that under these circumstances chlorite appears instead of augite, etc., and albite instead of calcic feldspar. This author considers that the formation of albite is aided by "transvaporization" of sea-water and states that this is the process of spilite formation investigated by Amstutz. It certainly cannot apply to Amstutz's (1954) Verrucano spilites which are of epicontinental type. Rittman's theory involves the retention of water, but "carbon dioxide and the other volcanic gases (HCl, H_2S, H_2, etc.) and gas transferred substances ($FeCl_3$, $MnCl_2$, $SiCl_4$, etc.) escape from the lava and form with sea-water pneumatolytic and hydrothermal solutions immediately at the roof of the outflowing lava". Rittmann believes that the chemically active solutions remain in contact with the lava in deep water and bring about reactions of the type andesine + augite + water + CO_2 = albite + epidote + actinolite + kaolinite + silica + calcite which he regards as a spilite reaction. Probably the greatest single difficulty in these deep-sea theories is that the formation of spilites is clearly not dependent on an abyssal environment. The sea-water diffusion theories are not of general application because some spilitic lavas are associated with non-marine environments (e.g., Dziedzicowa, 1958) and others may have been subaerial. Furthermore, there are now several records of non-spilitic submarine lavas. The pillow lavas from the mid-Atlantic ridge (Shand, 1949) appear to be normal basaltic types with olivine and calcic feldspar. The spilitic intrusion studied by Duschatko and Poldervaart (1955) contains sulphate minerals which may indicate addition from gypsum beds, but no case can be made there for the derivation of soda from the immediate environment.

So far we have considered mainly examples of spilite formation in the presence of volatiles at least partly juvenile in character. But the suggestions of Daly and Gilluly on the importance of resurgent waters may involve post-consolidational alteration. Gilluly, in fact, gives a convincing example of such late alteration in the Oregon spilites. It is an impressive fact that spilitic rocks are often associated with tuffs and greywackes (Tyrrell, 1933). Pettijohn and Bastron (1959) state that "the close association of many graywackes with spilitic rocks suggests that the sodium problem [in greywackes] is related to the origin of spilites". These sediments are often albite-bearing and may show many signs of extensive post-depositional mineral alteration, due to processes of diagenesis or low-grade metamorphism. It is an equally impressive fact that the post-depositional mineral assemblages of these sediments are often similar to those of the associated spilites. There is often clear evidence of growth of minerals such as albite, chlorite, epidote, prehnite, pumpellyite and zeolites in sediments after deposition. Coombs et al. (1959) offer examples from New Zealand. As this alteration is so extensive within a sedimentary pile it is clearly too much to expect it to result exclusively from the action of magmatic volatiles. Probably most of the fluid available for reaction and as a medium for the transfer of other components is connate in origin. The pore-water in geosynclinal sediments is often dismissed as sea-water, but it is likely that this water varies considerably in composition, the variation probably reflecting diagenetic or metamorphic changes in the rock (White, 1957). Controls such as pH, P_{load} and P_{H_2O} will have important influences on post-depositional mineral reactions in sediments. The work of Coombs in New Zealand has clearly demonstrated systematic changes in mineralogy with depth. Recently, Stoiber and Davidson (1959) have recognized systematic changes with depth in the amygdule minerals in basic lavas in Michigan. The Tamworth Group in which spilites occur at Nundle was probably overlain by a cover of the order of 40,000 feet of Devonian, Carboniferous and Permian sediments. Dr. K. A. W. Crook (pers. comm.) has found diagenetic mineral sequences in these rocks. Calcic zeolites of the types found in the New Zealand examples (Coombs et al., 1959) have been observed by Dr. Crook in the rocks above the Tamworth Group, but are rare in the spilites and greywackes of the Tamworth Group itself.

There must be a continuous sequence from diagenesis to low-grade metamorphism and most of the mineral facies of spilites are akin to those of the Zeolite Facies and Greenschist Facies, appropriate to these environments. Quite clearly, diagenesis cannot be invoked to account for intrusive spilites such as those described by Duschatko and Poldervaart (1955). I think, however, that post-depositional diagenetic alteration offers possibilities as an explanation of the mineral changes in many geosynclinal spilites and greywackes. One great deficiency in the literature is the all too common omission of details concerning the mineralogy of sediments associated with spilites. The occurrence of rocks containing calcic feldspars associated with spilites is difficult to explain on the diagenetic theory. While on the subject of post-depositional alteration it is interesting to recall that Termier (1898) proposed a mechanism involving circulating ground-water in the zone of weathering to account for the spilites at Pelvoux. Dziedzicowa's (1958) spilites had earlier been regarded as weathering products.

Many spilites have been involved in deformative movements which have converted the rocks to greenschists. As a result some people (e.g., Sundius, 1915; Fairbairn, 1934) have regarded spilites as merely regionally metamorphosed basalts. As, however, there are numerous examples of undeformed spilites with similar mineral assemblages, I cannot believe that regional deformation is in any way essential to the formation of these rocks. I think there would be fairly general agreement with Rittmann's (1958) view that low-grade regional metamorphism of spilites is reflected mainly in changes in fabric, not in mineralogy.

I cannot see how any single hypothesis can account for all the occurrences of spilitic rocks. It is clear in some cases that volatiles have concentrated in the magma, leading possibly to direct crystallization of "spilite" minerals or to replacement of earlier anhydrous phases. In other cases an equally good argument can be made for post-consolidational changes. It is important to recognize that these processes are convergent as far as mineral products are concerned. In all of these processes the fluids available enter into mineral reactions and also serve as carriers. The heterogeneity of spilitic bodies, with some parts rich in soda and poor in lime, other parts rich in lime and poor in soda, and so on, is surely related to the transfer of materials in solution.

Two main spilite associations have to be explained. We have seen that in geosynclinal regions spilites may occur in close proximity to ultrabasic bodies—the ophiolite association—or with keratophyres and other more acid rocks. Both of these associations are too common to be purely accidental, although, in the case of the occurrence of ultrabasic bodies with spilites there may be rather variable time relations between the two rock types. For this latter reason Turner and Verhoogen (1951) regard spilites and serpentinites as belonging to different geosynclinal associations. European petrographers (e.g., Gees, 1956) incline to the view that all the ophiolites are derived from ultrabasic magma through gravity differentiations. This view raises the problem of the nature of ultrabasic "magma" and whether crystal sinking is possible in such a medium—a fascinating problem which I cannot pursue here. However, I find it difficult to reconcile differentiation from ultrabasic magma with the observations of Vuagnat and others that diabases are the most abundant ophiolitic rocks in the Pennine Alps. Van Bemmelen (1950) suggests that the ophiolite association represents "a geochemical culmination of cafemic constituents in front of acidification and migmatization of the crustal base", in other words, a "basic front".

The spilite-keratophyre association almost certainly involves differentiation from a basic magma. In view of the lack of evidence of a parental spilite magma it seems most reasonable to postulate the spilite-keratophyre group as derived from basaltic magma. It is instructive to compare spilite-keratophyre association with commonly accepted differentiation sequences. Figure 5 shows diagrammatically relations between SiO_2 and the ratios $CaO/CaO + Na_2O + K_2O$ and $Na_2O/Na_2O + K_2O$. The examples from California, taken as typical of a basalt-andesite-rhyolite sequence, shows a significantly different variation from that in the suite from Ascension and St. Helena. Examples of analyses

of spilite-keratophyre suites are unfortunately rare, and those that have been studied may be imperfectly sampled. A great deal of chemical information is available on the rocks of the Lahn region, but, in view of the doubt about the significance of weilburgites, I have avoided this suite. The spilite association from Crimea is not completely satisfactory because Loewinson-Lessing and Diakonova-Savelieva (1933) suggest that this suite belongs to a group formed through mixing of acid and basic magmas. I have used this Crimean suite simply because I know of no other more suitable example offering a
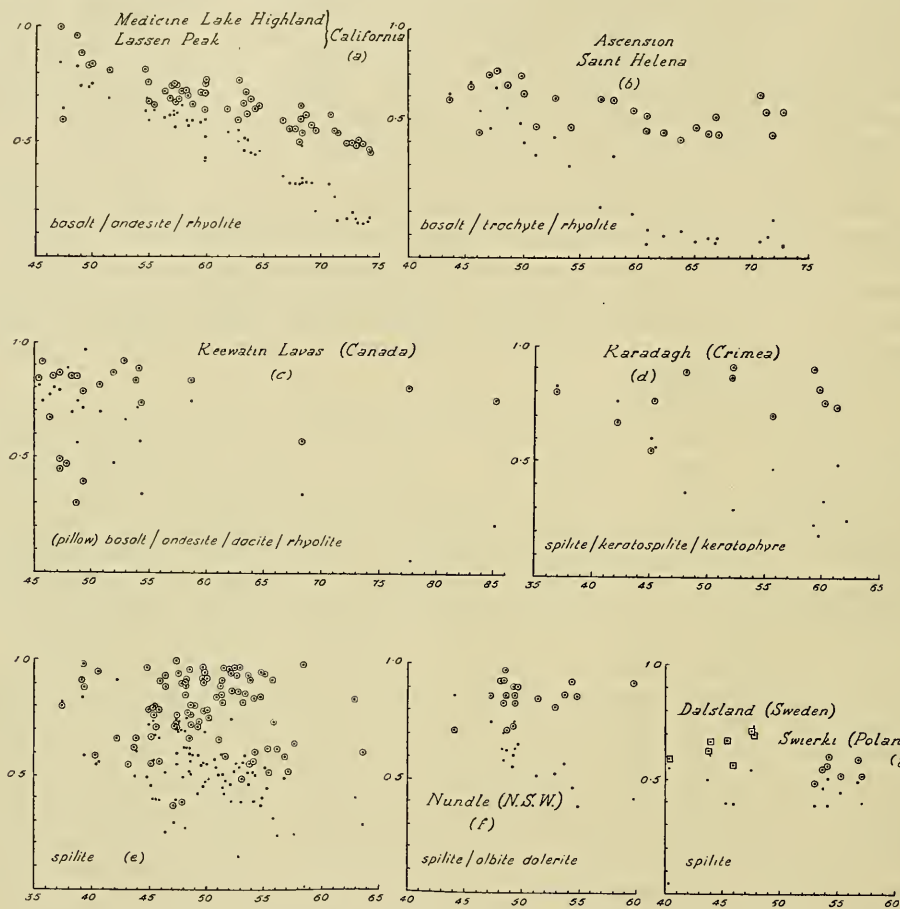
Figure 5.—Variation diagrams showing relations between typical calc-alkaline (a) and alkaline (b) suites and spilitic associations. In each case the horizontal scale represents SiO_2 (wt. %) and the vertical scale represents the ratios Na_2O/Na_2O+K_2O (enclosed spots) and $CaO/CaO+Na_2O+K_2O$ (spots). References for (a)—Anderson (1941) and Williams (1932), for (b)—Daly (1925, 1927), for (c) Satterly (1941) and Wilson (1938), for (d)—Loewinson-Lessing and Diakonova-Savelieva (1933), for (e)—Table 2, for (f)—unpublished analyses, for (g)—Dziedzicowa (1958) and Van Overeem (1948).

comparable number of analyses. It should be at once evident that there is a greater scatter of points in the spilite-keratophyre diagram than in the diagrams for normal differentiation. Spilites and albite dolerites from Nundle display more regular variations than the Crimean spilites, but the Nundle suite still shows definite departure in the $Na_2O/Na_2O + K_2O$ ratio from those of the Pacific and Atlantic suites. There is even a suggestion of an increase in soda relative to total alkalis with increase in SiO_2 at Nundle; this is hardly the usual pattern in differentiation sequences. I must emphasize, however, that the Nundle area is still incompletely sampled. The Keewatin lavas, though

not regarded as spilitic by Canadian geologists, also show a wide scatter. Many of these lavas contain sodic felspar and signs of alteration of primary minerals are common. The variations in the Keewatin basalt-andesite-rhyolite association are certainly different from those in the more recent Californian suite.

Spilites and keratophyres are doubtless related genetically, but the high soda to total alkali relation in the more acid types sampled and the departure from regular serial variation in lime and alkalis seen in Figure 5 are unusual in differentiation series. Are these features superimposed on the main differentiations? Are spilites and kerato- phyres essentially basaltic and andesitic rocks in which there has been re-distribution of material and adjustment to low temperature, hydrous conditions? Such re-distribution might occur under the influence of any of several processes, late-magmatic, hydro- thermal, or diagenetic/metamorphic. A suggestion along these lines, interpreting spilite as a modified basalt, was put forward by R. A. Daly years ago. I think the idea has a great deal to recommend it. Perhaps the main reason why spilitic rocks are so common in geosynclinal associations is because these environments offer such consider- able opportunities for post-consolidational alteration.

References.

AGRELL, S. O., 1939.—The adinoles of Dinas Head, Cornwall. *Miner. Mag.*, 25 : 305-337.

ALEKSANDROV, A. I., 1956.—[Shungite from rocks of the spilite-albitophyre formation in the region of Krasnouralsk (Middle Urals).] *Izvest. Akad. Nauk SSSR, Ser. Geol.*, 1956, no. 5 : 99-103.

ANDERSON, C. A., 1941.—Volcanoes of the Medicine Lake Highland, California. *Univ. of Calif. Publ., Bull. Dept. Geol. Sci.*, 25, no. 7 : 347-422.

AMBROSINUS, B., 1648.—U. Aldrovandi . . . *Musaeum Metallicum.* Lib. IV, Cap LXVII : 882- 883. Bologna.

AMSTUTZ, G. C., 1953.—Geochemistry of Swiss lavas. *Geochim. et Cosmochim. Acta,* 3 : 157-168.

————, 1954.—Geologie und Petrographie der Ergussgesteine im Verrucano des Glarner Freiberges. *Vulkaninstitut Imm. Friedlaender. Publ.* No. 5 (Zürich).

————, 1958.—Spilitic rocks and mineral deposits. *Bull. Missouri School of Mines and Metallurgy,* Tech. ser., no. 96, 11 pp.

BACKLUND, H. G., 1930.—Die Magmagesteine der Geosynklinale von Nowaja Semlja. *Rept. Sci. Results Norwegian Exped. to Nowaya Zemlya, 1921.* No. 45, 63 pp.

————, 1932.—Das Alter des "metamorphen Komplexes" von Franz Josef Fjord in Ost- Grönland. *Meddelelser om Grønland,* 87, no. 4, 119 pp.

BAILEY, E. B., 1936.—Sedimentation in relation to tectonics. *Bull. Geol. Soc. Amer.*, 47 : 1713- 1726.

————, and GRABHAM, G. W., 1909.—Albitization of basic plagioclase felspars. *Geol. Mag.,* decade 5, vol. 6 : 250-256.

BALSILLIE, D., 1932.—The Ballantrae Igneous Complex, South Ayrshire. *Geol. Mag.,* 69 : 107-131.

————, 1937.—Further observations on the Ballantrae Igneous Complex, South Ayrshire. *Geol. Mag.,* 74 : 20-33.

BANKS, M. R., 1956.—The Middle and Upper Cambrian Series (Dundas Group and its correlates) in Tasmania. *Int. Geol. Congr., 20th Sess., Mexico.* El Sistema Cambrico, su Paleogeografia y el Problema de su Base. Tomo II.—Parte II : Australia, America, pp. 165-212.

BARTH, T. F. W., 1936.—Structural and petrologic studies in Dutchess County, New York. Part II : Petrology and metamorphism of the Paleozoic rocks. *Bull. Geol. Soc. Amer.,* 47 : 775-850.

BARTRUM, J. A., 1936.—Spilitic rocks in New Zealand. *Geol. Mag.,* 73 : 414-423.

BATTEY, M. H., 1955.—Alkali metasomatism and the petrology of some keratophyres from New Zealand. *Geol. Mag.,* 92 : 104-126.

————, 1956.—The petrogenesis of a spilitic rock series from New Zealand. *Geol. Mag.,* 93 : 89-110.

BEARTH, P., 1959.—über Eklogite, Glaukophanschiefer und metamorphe Pillowlaven. *Schweiz. Min. Petr. Mitt.,* 39 : 267-286.

BENSON, W. N., 1913a.—Spilite lavas and radiolarian rocks in New South Wales. *Geol. Mag.,* decade 5, vol. 10: 17-21.

————, 1913b.—The geology and petrology of the Great Serpentine Belt of New South Wales. Part II. The geology of the Nundle district. PROC. LINN. SOC. N.S.W., 38: 569-596.

————, 1913c.—Idem. Part III. Petrology. *Ibid.,* 38: 662-724.

————, 1915a.—Idem. Part IV. The dolerites, spilites and keratophyres of the Nundle district. *Ibid.,* 40: 122-173.

————, 1915b.—Idem. Part V. The geology of the Tamworth district. *Ibid.,* 40: 540-624.

————, 1916.—The general geology of the Gloucester district. *Jour. Proc. Roy. Soc. N.S.W.,* 50, pp. xxxii-xxxv.

BESKOW, G., 1929.—Södra Storfjället im südlichen Lappland. Eine petrographische und geologische Studie im zentralen Teil des Skandinavischen Hochgebirges. *Sveriges Geol. Unders., Årsbok,* 21 (1927), no. 5, 335 pp.

BLOXAM, T. W., 1958.—Pumpellyite from south Ayrshire. *Miner. Mag.,* 31: 811-813.

————, 1960.—Pillow-structure in spilitic lavas at Downan Point, Ballantrae. *Trans. Geol. Soc. Glasgow,* 24: 19-26.

BLYTH, F. G. H., 1935.—The basic intrusive rocks associated with the Cambrian inlier near Malvern. *Quart. Jour. Geol. Soc. Lond.,* 91: 463-476.

BONNARD, A. H. DE, 1819.—Article "Roches" vol. 29 (especially pp. 370-373), *Nouveau dictionnaire d'histoire naturelle appliquée aux arts . . .* par une Société de naturalistes et d'agriculteurs. Paris. 1816-1819. 36 vols.

BONNEY, T. G., and RAISIN, C. A., 1893.—On the so-called spilites of Jersey. *Geol. Mag.,* dec. 3, vol. 10: 59-64.

BRAUNS, R., 1909.—Beiträge zur Kenntnis der chemischen Zusammmsetzung der devonischen Eruptivgesteine im Gebiete der Lahn und Dill. *Neues Jahrb. f. Min. Geol. u. Pal.,* 27, B-B., pp. 261-325.

BRONGNIART, A., 1813.—Essai d'une classification minéralogique des roches melangées. *Jour. des Mines,* 34: 5-48.

————, 1827.—Article "Roches", vol. 46, pp. 1-140, especially pp. 98-100 (spilite) and pp. 111-112 (variolite). Article "Spilite", vol. 50, pp. 261-265. *Dictionnaire des sciences naturelles . . .* Strasbourg and Paris. 60 vols., 1816-1830. N.B. The article "Roches" also appeared separately as Classification et caractères minéralogiques des roches homogènes et héterogènes. Paris, 1827.

————, 1828.—Article "Variolite", vol. 56, p. 496. *Dictionnaire des sciences naturelles.*

BRUNN, J. H., 1954.—Les éruptions ophiolithiques dans le NW de la Grèce; leurs relations avec l'orogénèse. *C.R. Int. geol. Congr., 19th Sess., Algiers, 1952,* fasc. 17: 19-27.

BUBNOFF, S. VON, 1937.—Die Halbinsel Kola. *Geol. Rundschau,* 28: 1-47.

BUCH, L. VON, 1830.—Uber einige geognostische Erscheinungen in der Umgebung des Luganer Sees in der Schweiz. *Abhandl. Akad. Wiss. Berlin* (for 1827), pp. 193-204.

BURRI, C., and NIGGLI, P., 1945.—Die jungen Eruptivgesteine des mediterranen Orogens. I. *Vulkaninst. Imm. Friedländer,* Publ. no. 3 (Zürich).

CADISCH, J., 1953.—*Geologie der schweizer Alpen.* Basel. Wepf and Co.

CARSTENS, C. W., 1924.—Der unterordovicische Vulkanhorizont in dem Trondhjemgebiet. *Norsk. geol. Tidsskr.,* 7: 185-269.

ČEPEK, L., HYNIE, O., KODYM, O., and MATEJKA, A., 1936.—Vysvetlivky ke geologické mape Československé Republiky List Kladno 3952. *Knihovna Statn. geol. Ustavu Česk. Republ.,* svazek 17.

CHENEVOY, M., 1958.—Sur l'importance et les caractères du paléovolcanisme en Limousin septentrional (Massif Central français). *Bull. Soc. géol. France,* ser. 6, t. 8: 113-122.

CHUMAKOV, A. A., 1940.—On the origin of sodium in spilites. *Izvest. Akad. Nauk SSSR, Ser. Geol.,* 1940, no. 2: 40-43.

CISSARZ, A., 1928.—Petrographische Untersuchungen von Sedimentgesteinen aus Nowaja Semlja und deren metamorphe Umwandlungen. *Rept. Sci. Results Norwegian Exped. to Novaya Zemlya, 1921,* no. 37, 66 pp.

COLE, G. A. J., and GREGORY, J. W., 1890.—On the variolitic rocks of Mont Genèvre. *Quart. Jour. Geol. Soc. London,* 46: 295-332.

COOMBS, D. S., 1953.—The pumpellyite mineral series. *Miner. Mag.,* 30: 113-135.

————, ELLIS, A. J., FYFE, W. S., and TAYLOR, A. M., 1959.—The zeolite facies, with comments on the interpretation of hydrothermal syntheses. *Geochim. et Cosmochim. Acta,* 17: 53-107.

CORIN, F., 1935.—Découverte d'une "série spilitique" et de "laves en coussins" (pillow lavas) en Hesbaye. *Acad. roy. Belgique. Bull.,* Cl. Sci., ser. 5, t. 21: 667-668.

COTTA, B. VON, 1862.—*Die Gesteinslehre.* Freiberg.

DALY, R. A., 1925.—The geology of Ascension Island. *Proc. Amer. Acad. Arts & Sci.,* 60: 3-80.

————, 1927.—The geology of Saint Helena Island. *Ibid.,* 62: 31-92.

————, 1933.—*Igneous rocks and the depths of the earth.* New York and London. McGraw-Hill.

DAVID, T. W. E., 1896.—The occurrence of radiolaria in Palaeozoic rocks in N.S. Wales. PROC. LINN. SOC. N.S.W., 21: 553-570.

DAVIES, R. G., 1959.—The Cader Idris granophyre and its associated rocks. *Quart. Jour. Geol. Soc. London*, 115 : 189-216.

DELESSE, A., 1857.—Métamorphisme des Roches. *Annales des Mines*, ser. 5, t. 12 : 417-515.

DEN TEX, E., 1950.—Les roches basiques et ultrabasiques des Lacs Robert et le Trias de Chamrousse (Massif de Belledonne). Étude pétrologique et géologique. *Leidse Geol. Mededelingen*, 15 : 1-204.

DE ROEVER, W. P., 1942.—Olivine basalts and their alkaline differentiates in the Permian of Timor. *Geol. Exped. to Lesser Sunda Islands* (H. A. Brouwer), vol. 4 (not seen).

———, 1947.—Igneous and metamorphic rocks in eastern Central Celebes. *Geol. Explor. in Island of Celebes* (H. A. Brouwer), pp. 67-173.

DEWEY, H., and FLETT, J. S., 1911.—British pillow-lavas and the rocks associated with them. *Geol. Mag.*, dec. 5, vol. 8 : 202-209, 241-248.

DONNAY, J. D. H., 1940.—Width of albite-twinning lamellae. *Amer. Mineral.*, 25 : 578-586.

DUBERTRET, L., 1954.—Basaltes et roches vertes du Liban, de Syrie et du Hatay (ancien Sandjak d'Alexandrette, Turquie). *Int. Geol. Congr., C.R. 19th Sess., Algiers*, 1952, fasc. 17 : 29-36.

DUPARC, L., and GROSSET, A., 1916.—*Recherches géologiques et pétrographiques sur le district minier de Nicolai-Pawda.* Geneva and Paris.

DURRELL, C., 1940.—Metamorphism in the southern Sierra Nevada northeast of Visalia, California. *Univ. Calif. Dept. Geol. Sci., Bull.*, 25 : 1-118.

DUSCHATKO, R. W., and POLDERVAART, A., 1955.—Spilitic intrusion near Ladron Peak, Socorro County, New Mexico. *Bull. Geol. Soc. Amer.*, 66 : 1097-1108.

DZIEDZICOWA, H., 1958.—Metasomatoza "melafirów" permskich ze Swierków na Dolnym Slasku. *Rocznik Polsk. Tow. Geol.*, 28 : 79-106.

ECKERMANN, H. VON., 1936.—The Loos-Hamra region. *Geol. Fören. Stockholm Förh.*, 58 : 129-343.

EMMONS, R. C., 1943.—The universal stage. *Geol. Soc. Amer., Memoir 8.*

ESKOLA, P., 1925.—On the petrology of eastern Fennoscandia. I. The mineral development of basic rocks in the Karelian formations. *Fennia*, 45, no. 19, 93 pp.

———, VUORISTO, U., and RANKAMA, K., 1937.—An experimental illustration of the spilite reaction. *Bull. Comm. géol. Finlande*, no. 119 : 61-68.

FAIRBAIRN, H. W., 1934.—Spilite and the average metabasalt. *Amer. Jour. Sci.*, ser. 5, 27 : 92-97.

FEARNSIDES, W. G., 1905.—On the geology of Arenig Fawr and Moel Llyfnant. *Quart. Jour. Geol. Soc. London*, 61 : 608-637.

———, and TEMPLEMAN, A., 1932.—A boring through Edale Shales to Carboniferous Limestone and pillow lavas, at Hope Cement Works, near Castleton, Derbyshire. *Proc. Yorks. Geol. Soc.*, 22 : 100-121.

FLAHERTY, G. F., 1934.—Spilitic rocks of southeastern New Brunswick. *Jour. Geol.*, 42 : 785-808.

FLETT, J. S., 1907.—*In* The geology of the country around Plymouth and Liskeard. *Mem. Geol. Surv. England and Wales.*

FLETT, J. S., 1909.—*In* The geology of the country around Bodmin and St. Austell. *Mem. Geol. Surv. England and Wales.*

FLETT, J S., 1911.—*In* The geology of Knapdale, Jura and north Kintyre. *Mem. Geol. Surv. Scotland.*

GARDINER, C. I., and REYNOLDS, S. H., 1912.—The Ordovician and Silurian rocks of the Kilbride Peninsula, Mayo. *Quart. Jour. Geol. Soc. London*, 68 : 75-101.

———, and ———, 1914.—The Ordovician and Silurian rocks of Lough Nafooey area (County Galway). *Quart. Jour. Geol. Soc. London*, 70 : 104-118.

GAY, P., 1956.—A note on albite twinning in plagioclase felspars. *Miner. Mag.*, 31 : 301-305.

GEES, R. A., 1956.—Ein Beitrag zum Ophiolith-Problem behandelt an einigen Beispielen aus dem Gebiet von Klosters-Davos (Graubünden). *Schweiz. Min. Petr. Mitt.*, 36 : 454-488.

GEIJER, P., 1916.—Notes on albitization and the magnetite-syenite porphyries. *Geol. Fören. Stockholm Förh.*, 28 : 243-264.

GEIKIE, A. (editor), 1907.—*A journey through England and Scotland to the Hebrides in 1784.* B. Faujas de Saint Fond. 2 vols. Glasgow.

GILLULY, J., 1935.—Keratophyres of eastern Oregon and the spilite problem. *Amer. Jour. Sci.*, ser. 5, vol. 29 : 225-252, 336-352.

GINZBERG, A. S., 1934.—[The petrography of the Republic of Armenia.] *The Petrography of the USSR*, ed. by F. Loewinson-Lessing, Series I, Regional Petrography, vol. 2, Petrogr. Inst. Acad. Sci. USSR, 127 pp.

GJELSVIK, T., 1958.—Extremely soda rich rocks in the Karelian zone, Finnmarksvidda, Northern Norway. A contribution to the discussion of the spilite problem. *Geol. Fören. Stockholm Förh.*, 80 : 381-406.

GÖTZ, H., 1937.—Die Keratophyre der Lahnmulde. *Tschermaks Min. Petr. Mitt.*, 49 : 168-215.

GREENLY, E., 1919.—The geology of Anglesey. Vol. I. *Mem. Geol. Surv. England & Wales.*

GREGORY, J. W., 1912.—The structural and petrographic classifications of coast-types. *Scientia* (Bologna), vol. 11, anno 6, 21 : 36-63.

GRINDLEY, G. W., 1958.—The geology of the Eglinton Valley, Southland. *N.Z. Geol. Surv., Bull.*, n.s. 58, 68 pp.

GRUBENMANN, U., 1909.—Beitrag zur Geologie des Unterengadins. *Beitr. zur geol. Karte der Schweiz,* no. 23.

GRUNAU, H., 1947.—*Geologie von Arosa (Graubünden). Mit besonderer Berücksichtigung des Radiolaritproblems.* Diss. Univ. Bern.

GUEYMARD, 1850.—Mémoire sur les variolites du Drac (spilites). *Annales des Mines,* ser. 4, t. 18 : 41-59.

GÜMBEL, C. W., 1874.—Die paläolithischen Eruptivgesteine des Fichtelgebirges.   München (esp. p. 43).

GUPPY, E. M., and SABINE, P. A., 1956.—Chemical analyses of igneous rocks, metamorphic rocks and minerals, 1931-1954. *Mem. Geol. Surv. Gt. Britain.*

————, and THOMAS, H. H., 1931.—Chemical analyses of igneous rocks, metamorphic rocks and minerals. *Mem. Geol. Surv. Gt. Britain.*

HACKMAN, V., 1927.—Studien über den Gesteinsaufbau der Kittilä-Lappmark. *Bull. Comm. géol. Finlande,* no. 79, pp. 106.

HEJTMAN, B., 1954.—Ordovické polstárové Lávy mezi obcí Točníkem a mestem Zebrákem. *Acta Univ. Carolinae, Geol.,* 9 : 3-36.

HENDRIKS, E. M. L., 1939.—The Start-Dodman-Lizard boundary-zone in relation to the Alpine structure of Cornwall. *Geol. Mag.,* 76 : 385-402.

HENTSCHEL, H., 1952a.—Zur Petrographie des Diabas-Magmatismus im Lahn-Dill-Gebiet. *Zeits. Deutsch. Geol. Gesell.,* 104 : 238-246.

————, 1952b.—"Weilburgit" und "Schalstein." *Zeits. Deutsch. Geol. Gesell.,* 104 : 257-259.

————, 1953.—Zur Frage der Chlorit- und Karbonat-Bildung in spilitischen Gesteinen. *Fortschr. Miner.,* Bd. 31 : 35-37.

HESS, H. H., 1941.—Pyroxenes of common mafic magmas. *Amer. Mineral.,* 26 : 515-535, 573-594.

————, 1955.—Serpentines, orogeny, and epeirogeny. *Geol. Soc. Amer., Spec. Pap.,* 62 : 391-408.

HEY, M. H., 1954.—A new review of the chlorites. *Miner. Mag.,* 30 : 277-292.

HOCHSTETTER, F. VON., 1864.—*Geologie von Neuseeland. Beiträge zur Geologie der Provinzen Auckland und Nelson. Reise der österreich. Fregatte Novara um die Erde.* Geologischer Teil. Band I. Abt. I. Wien.

HOLZNER, J., 1933.—Über den Stilpnomelan von Grube Theodor (Lahngebiet) und einen beim Trennen mit Clericilösung auftretenden Basenaustausch. *Neues Jahrb. Min.,* B.-B., 66, Abt. A., pp. 213-225.

————, 1938.—Eisenchlorit aus dem Lahngebiet: chemische Formel und Valenzausgleich bei den Eisenchloriten. *Neues Jahrb. Min.* B.-B., 73, Abt. A, pp. 389-417.

JAFFÉ, F. C., 1955.—Les ophiolites et les roches connexes de la région du Col des Gets (Chablais, Haute Savoie). *Schweiz. Min. Petr. Mitt.,* 35 : 1-150.

JOHANNSEN, A., 1937.—*A descriptive petrography of the igneous rocks.* Vol. III. The intermediate rocks. Chicago.

JOHNSTON, R. M., 1888.—*Systematic account of the geology of Tasmania.* Hobart.

KARL, F., 1954.—Über Hoch- und Tieftemperaturoptik von Plagioklasen und deren petrographische und geologische Auswertung am Beispiel einiger alpiner Ergussgesteine. *Tschermaks Min. Petr. Mitt.,* ser. 3, 4 : 320-328.

KENNEDY, G. C., 1955.—Some aspects of the role of water in rock melts. *Geol. Soc. Amer., Special Paper* 62 : 489-504.

KHARITONOV, L. J., 1937.—Geological description of the Chiobino-Pokrovskoye district. *Int. Geol. Congr. XVII Sess., Moscow,* The Northern Excursion. The Karelian ASSR, pp. 59-77.

KOZLOWSKI, S., 1958.—Wulkanizm permski w rejonie Gluszycy i Swierkow na Dolnym Slasku. *Rocznik Polsk. Tow. Geol.,* 28 : 5-61.

KUPLETSKY, B. M., 1932.—Zur Erforschung der Diabasgesteine von Novaja Zemlja. *Petrogr. Inst., Akad. Nauk SSSR, Trudy,* 2 : 5-15.

KURSHAKOVA, L. D., 1958.—[Metamorphic alterations of ore-containing spilites in the Buribayevsky chalcopyrite deposit.] *Izvest. Akad. Nauk SSSR, Ser. Geol.,* 1958, no. 8 : 57-64.

KUTINA, J., 1955.—Genetische Diskussion der Makrotexturen bei der geochemischen Untersuchung des Adalbert-Hauptganges in Príbram. *Chemie der Erde,* 17 : 241-323.

LEHMANN, E., 1933.—Über "Diabase" und Schalsteine aus dem Mitteldevon des Lahn-Dillgebiets. *Ber. Oberhess. Gesell. f. Natur- und Heilkunde zu Giessen,* N.F., Naturw. Abt., 15 : 307-334.

————, 1940.—*Eruptivgesteine und Eisenerze im Mittel- und Oberdevon der Lahnmulde.* Wetzlar. (Not seen.)

————, 1949.—Das Keratophyr-Weilburgit-Problem.   *Heidelberger Beitr. zur Min. Petr.,* 2 : 1-166.

————, 1952a.—The significance of the hydrothermal stage in the formation of igneous rocks. *Geol. Mag.,* 89 : 61-69.

————, 1952b.—Beitrag zur Beurteilung der paläozoischen Eruptivgesteine Westdeutschlands. *Zeits. Deutsch. Geol. Gesell.,* 104 : 219-237.

————, 1952c.—Diskussionbemerkung zum Thema "Weilburgite" und "Schalstein." *Zeits. Deutsch. Geol. Gesell.,* 104 : 255-256.

LEWIS, J. V., 1914.—Origin of pillow lavas. *Bull. Geol. Soc. Amer.*, 25: 591-654.

LOEWINSON-LESSING, F., 1901.—Lexique pétrographique. *Int. Geol. Congr., C.R. 8th Sess.*, France, 1900, f. 2: 1003-1302.

LOEWINSON-LESSING, F. Y., and DIAKONOVA-SAVELIEVA, E. N., 1933.—Le groupe paléo-volcanique du Karadagh en Crimée. *Petrogr. Inst. Akad. Nauk SSSR*, Leningrad, 1933, 151 pp.

McCALLIEN, W. J., 1936.—A note on Dalradian pillow lavas, Strabane, Co. Tyrone. *Proc. Roy. Irish Acad.*, 43, B: 13-22.

MASHKOVZEV, S., 1933.—Materials for the geology of the eastern slope of the northern Ural. *Trans. United Geol. Prosp. Serv. USSR*, 254, 66 pp.

MICHEL-LÉVY, A., 1889.—*Structures et classification des roches éruptives*. Paris.

NAUMANN, C. F., 1850.—*Lehrbuch der Geognosie*. Bd. I. Leipzig.

NETELBEEK, T. A. F., 1951.—*Géologie et pétrologie de la région entre Vezzani et Lugo di Nazza (Corse)*. Diss. Amsterdam.

NICHOLLS, G. D., 1959.—Autometasomatism in the Lower Spilites of the Builth Volcanic Series. *Quart. Jour. Geol. Soc. London,* 114 (for 1958): 137-161.

NIGGLI, P., 1952.—The chemistry of the Keweenawan lavas. *Amer. Jour. Sci.*, Bowen Vol., pt. 2: 381-412.

————, DE QUERVAIN, F., and WINTERHALTER, R. U., 1930.—Chemismus schweizerischer Gesteine. *Beitr. Geol. der Schweiz*, geotechn. Serie, 14 Lieferung, 389 pp. (esp. p. 219).

NOCKOLDS, S. R., 1954.—Average chemical compositions of some igneous rocks. *Bull. Geol. Soc. Amer.*, 65: 1007-1032.

NORIN, E., 1937.—Geology of western Quruq Tagh, eastern T'ien-shan. *Rept. Sci. Exped. to N.W. Provinces of China under leadership of Dr. Sven Hedin* (Stockholm), III, Geology, I, xv + 195 pp.

PARK, C. F., JR., 1946.—The spilite and manganese problems of the Olympic Peninsula, Washington. *Amer. Jour. Sci.*, 244: 305-323.

PELLIZER, R., 1954.—Le spiliti di Comeglians nella media val Degano (Carnia). *Soc. Miner. Italiana, Rend.*, an. 10: 405-414.

PERRIN, R., and ROUBAULT, M., 1941.—Quelques observations sur le spilite de Montvernier (Savoie). *Bull. Soc. Hist. Nat. Toulouse*, 76; 161-171.

PETTIJOHN, F. J., and BASTRON, H., 1959.—Chemical composition of argillites of the Cobalt series (Precambrian) and the problem of soda-rich sediments. *Bull. Geol. Soc. Amer.,* 70: 593-600.

PICHAMUTHU, C. S., 1938.—Spilitic rocks from Chitaldrug, Mysore State. *Current Sci.* (Bangalore), 7: 55-57.

————, 1946a.—Cycles in Dharwar sedimentation. *Current Sci.*, 15: 273-274.

————, 1946b.—Quartz-keratophyres from Galipuje, Kadur district, Mysore. *Quart. Jour. Min. Met. Soc. India*, 18: 125-128.

PILGER, A., 1952.—Tektonik, Magmatismus und Vererzung, Zusammenhänge im ostrheinischen Schiefergebirge. *Zeits. Deutsch. Geol. Gesell.*, 104: 198-218.

RAMOS, J. R. DE A., 1958.—Reconhecimento geologico no Território de Rio Branco. *Noticia Geomorfolog.* (Campinas, Brazil), 1: 18-21.

REED, J. J., 1950.—Spilites, serpentinites and associated rocks of the Mossburn district, Southland. *Trans. Roy. Soc. N. Zealand,* 78: 106-126.

————, 1957.—Petrology of the Lower Mesozoic rocks of the Wellington district. *N. Zealand Geol. Surv., Bull.*, n.s., 57, 60 pp.

REINHARD, M., and WENK, E., 1951.—Geology of the colony of North Borneo. *Geol. Surv. Dept. Brit. Terr. in Borneo, Bull.* 1, xiv + 160 pp.

RICHARDS, H. C., and BRYAN, W. H., 1924.—The geology of the Silverwood-Lucky Valley area. *Proc. Roy. Soc. Queensland*, 36: 44-108.

RITSEMA, L., 1952.—*Geologie de la région de Corte (Corse)*. Diss. Amsterdam.

RITTMAN, A., 1940.—Studien an Eruptivgesteinen aus Ost-Grönland. *Meddelelser om Grønland,* 115, no. 1, 156 pp.

————, 1951.—Orogénèse et volcanisme. *Archives des Sci.* (Geneva), 4: 273-314.

————, 1958.—Geosynclinal volcanism, ophiolites and Barramiya rocks. *Egyptian Jour. Geol.*, 2: 61-65.

RODOLICO, F., 1933.—Studi sulla datolite della formazione ofiolitica; datolite dell'Impruneta, Toscana. *Periodico Miner.*, 4: 1-14.

RONOV, A. B., 1946.—Hercynian volcanism of the Urals at the period of their geosynclinal subsidence, in the light of quantitative relations. *C.R. (Doklady) Acad. Sci. URSS*, 53: 649-652.

ROOTHAAN, H. P., 1919.—Petrographische Untersuchungen in den Bergen der Umgebung von Vals (Bündner Oberland). *Jahresber. der Naturforsch. Gesell. Graubündens*, N.F., 59.

ROSENBUSCH, H., 1887.—*Mikroskopische Physiographie der Mineralien und Gesteine*. Bd. II. *Massige Gesteine*. Stuttgart.

————, 1901.—*Elemente der Gesteinslehre*. 2nd edit. Stuttgart.

ROUTHIER, P., 1946.—L'association radiolarites-roches vertes dans les chaines géosynclinales: I. Observations géologiques en Corse at ailleurs. *C.R. Soc. géol. France*, no. 2: 26-28.

SARGENT, H. C., 1917.—On a spilitic facies of Lower-Carboniferous lava-flows in Derbyshire. *Quart. Jour. Geol. Soc. London*, 73 : 11-23.

SATTERLY, J., 1941.—Pillow lavas from the Dryden-Wabigoon area, Kenora district, Ontario. *Univ. Toronto Studies, Geol. Series*, no. 46 : 119-136.

SCHWARTZ, G. M., 1939.—Hydrothermal alteration of igneous rocks. *Bull. Geol. Soc. Amer.*, 50 : 181-238.

SCOTT, B., 1951a.—The petrology of volcanic rocks of south east King Island, Tasmania. *Pap. Proc. Roy. Soc. Tasmania*, 1950 : 113-136.

————, 1951b.—A note on the occurrence of intergrowth between diopsidic augite and albite and of hydrogrossular from King Island, Tasmania. *Geol. Mag.*, 88 : 429-431.

————, 1952.—The occurrence of pillow lavas near Penguin, Tasmania. *Pap. Proc. Roy. Soc. Tasmania*, 1951 : 123-125.

————, 1954.—The metamorphism of the Cambrian basic volcanic rocks of Tasmania and its relationship to the geosynclinal environment. *Pap. Proc. Roy. Soc. Tasmania*, 88 : 129-149.

SEMENENKO, N. P., 1955.—Classification universelle des roches magmatiques. *Sciences de la Terre* (Nancy), 1955 : 239-245.

SHAND, S. J., 1949.—Rocks of the mid-Atlantic Ridge. *Jour. Geol.*, 57 : 89-92.

SIRIN, N. A., 1937.—Geological and petrographical description of the gabbro intrusive body of Yalping-Ner in the northern Ural. *Inst. Petrogr. Acad. Sci. URSS, Trav.*, 11 : 17-69.

SLAVIK, F., 1908.—Spilitische Ergussgesteine im Präkambrium zwischen Kladno und Klattau. *Arch. naturw. Landesd. Böhmen*, 14, no. 2 : 1-176.

————, 1928.—Les "pillow-lavas" algonkiennes de la Bohême. *Int. Geol. Congr., 14th Sess., Spain*, 1926, f. 4 : 1389-1395.

————, 1945.—Basic igneous rocks of the northern Zelezne h-ory. *Vestnik Král. České Spolecnosti Nauk, Trida Mat.-Prirod-Rocnik*, 1945, no. 13, 9 pp.

SMULIKOWSKI, K., 1957.—Riebeckite secondaire dans les mélaphyres de Lomnica dans les Sudètes. *Schweiz. Min. Petr. Mitt.*, 37 : 565-566.

SPRY, A., 1954.—The thermal metamorphism of portions of the Woolomin Group in the Armidale district, N.S.W. Part I. The Puddledock area. *Jour. Proc. Roy. Soc. N.S.W.*, 87 : 129-136.

STAMP, L. D., and WOOLDRIDGE, S. W., 1923.—The igneous and associated rocks of Llanwrtyd (Brecon). *Quart. Jour. Geol. Soc. London*, 79 : 16-44.

STARK, J. T., 1938.—Vesicular dikes and subaerial pillow lavas of Borabora, Society Islands. *Jour. Geol.*, 46 : 225-238. (For discussion of this work see *Jour. Geol.*, 47, 1939, pp. 202-209.)

STEINMANN, G., 1905.—Geologische Beobachtungen in den Alpen. II. Die SCHARDT-sche Ueberfaltungstheorie und die geologische Bedeutung die Tiefseeabsätze und der ophiolithischen Massengesteine. *Ber. naturf. Gesell. Freiburg i B.*, 16 : 18-67.

————, 1927.—Die ophiolitischen Zonen in den mediterranen Kettengebirgen. *Int. Geol. Congr., C.R. XIV Sess., Spain*, 1926, f. 2 : 637-668.

STEPHENS, E. A., 1956.—The manganese deposits of North Borneo. *Int. Geol. Congr., 20th Sess., Mexico*, 1956. Symposium sobre yacimientos de manganeso, IV, Asia y Oceania, pp. 297-312.

STEVENS, N. C., 1952.—Ordovician stratigraphy at Cliefden Caves, near Mandurama, N.S.W. PROC. LINN. SOC. N.S.W., 77 : 114-120.

STOIBER, R. E., and DAVIDSON, E. S., 1959.—Amygdule mineral zoning in the Portage Lake lava series, Michigan copper district. Part I. *Econ. Geol.*, 54 : 1250-1277.

SUNDIUS, N., 1915.—Beitrage zur Geologie des südlichen Teils des Kirunagebiets. 4. Geologie des Kirunagebietes. *Vetensk. Prakt. Undersökn. i Lappland.* Stockholm.

————, 1930.—On the spilitic rocks. *Geol. Mag.*, 67 : 1-17.

SUZUKI, J., and MINATO, M., 1954.—Volcanic activity in Japan in the Palaeozoic era. *Int. Geol. Congr., C.R., 19th Sess., Algiers*, f. 17 : 209-211.

SZÁDECZKY-KARDOSS, E., 1958.—On the petrology of volcanic rocks and the interaction of magma and water. *Acta Geologica* (Budapest), 5 : 197-233.

TAKABATAKE, A., 1956.—Genesis of manganiferous iron deposits in Japan. *Int. Geol. Congr., 20th Sess., Mexico*, 1956. Symposium sobre yacimientos de manganeso. Tomo IV. Asia y Oceania, pp. 205-220.

TALIAFERRO, N. L., 1943.—Manganese deposits of the Sierra Nevada, their genesis and metamorphism. *Calif. Div. Mines, Bull.*, 125 : 277-332.

TEALL, J. J. H., 1894.—On greenstones associated with radiolarian cherts. *Trans. Roy. Geol. Soc. Cornwall*, 11 : 560-565.

TERMIER, H., and TERMIER, G., 1956a.—*L'évolution de la lithosphère. I. Pétrogénèse.* Paris.

————, 1956b.—*L'évolution de la lithosphère. II. Orogénèse.* Fasc. I. Paris.

————, 1957.—*L'évolution de la lithosphère. III. Orogénèse.* Fasc. II. Paris.

TERMIER, P., 1898.—Sur l'élimination de la chaux par metasomatose dans les roches éruptives basiques de la région du Pelvoux. *Bull. Soc. géol. France*, ser. 3, 26 : 165-192.

THOMAS, G. E., and THOMAS, T. M., 1956.—The volcanic rocks of the area between Fishguard and Strumble Head, Pembrokeshire. *Quart. Jour. Geol. Soc. London*, 112 : 291-311.

THOMAS, H. H., 1911.—The Skomer volcanic series (Pembrokeshire). *Quart. Jour. Geol. Soc. London*, 67: 175-212.

TOMKEIEFF, S. I., 1941.—Metasomatism in the basalt of Haddenrig quarry near Kelso and the veining of the rocks exposed there. *Miner. Mag.*, 26: 45-59.

————, and MARSHALL, C. E., 1940.—The Killough-Ardglass dyke swarm. *Quart. Jour. Geol. Soc. London*, 96: 321-338.

TROMP, S. W., 1948.—Shallow-water origin of radiolarites in southern Turkey. *Jour. Geol.*, 56: 492-494.

TURNER, F. J., 1948.—Mineralogical and structural evolution of the metamorphic rocks. *Geol. Soc. America*, Mem. 30.

————, and VERHOOGEN, J., 1951.—*Igneous and metamorphic petrology.* New York. McGraw-Hill.

TYRRELL, G. W., 1933.—Greenstones and greywackes. *Bull. Comm. geol. Finlande*, no. 102: 24-26.

VALLANCE, T. G., 1953.—Studies in the metamorphic and plutonic geology of the Wantabadgery-Adelong-Tumbarumba district, N.S.W. Part II. Intermediate-basic rocks. *Proc. Linn. Soc. N.S.W.*, 78: 181-196.

VALLET, J. M., 1950.—Étude géologique et pétrographique de la partie inférieure du Val d'Hérens et du Val d'Hérémence (Valais). *Schweiz. Min. Petr. Mitt.*, 30: 322-476.

VAN BEMMELEN, R. W., 1949.—*The geology of Indonesia.* Vol. IA. *General geology of Indonesia and adjacent archipelagoes.* The Hague.

————, 1950.—On the origin of igneous rocks in Indonesia. *Geol. en Mijnbouw*, 12 Jaarg., no 7: 207-220.

VAN DER KAADEN, G., 1951.—*Optical studies on natural plagioclase feldspars with high- and low-temperature optics.* Diss. Univ. Utrecht, 105 pp.

VAN DER WAALS, L., 1946.—*De geologie van een gebied ten noorden van la Spezia, zuid-oost Ligurie (Italië).* Diss. Univ. Amsterdam, 92 pp.

VAN OVEREEM, A. J. A., 1948.—*A section through the Dalformation. A contribution to the geology of Dalsland, S.W. Sweden.* Diss. Univ. Leiden, 131 pp.

VÄYRYNEN, H., 1928.—Geologische und petrographische Untersuchungen im Kainuugebiete. *Bull. Comm. géol. Finlande*, no. 78, 128 pp.

VOGT, T., 1927.—Sulitelmafeltets Geologi og Petrografi. *Norges Geol. Undersök*, no. 121, 560 pp. (esp. pp. 240-249).

VOISEY, A. H., 1939.—The Upper Palaeozoic rocks between Mount George and Wingham, N.S. Wales. *Proc. Linn. Soc. N.S.W.*, 64: 242-254.

VUAGNAT, M., 1943.—Les grès de Taveyannaz du val d'Illiez et leurs rapports avec les roches éruptives des Gêts. (Not seen.) *Schweiz. Min. Petr. Mitt.*, 23: 353-436.

————, 1946.—Sur quelques diabases suisses. Contribution à l'étude du problème des spilites et des pillow lavas. (Not seen.) *Schweiz. Min. Petr. Mitt.*, 26: 116-228.

————, 1947.—Sur le caractère spilitique des mélaphyres de la région du Pelvoux. *C.R. séances Soc. Phys. Hist. nat. Genève*, 64: 43.

————, 1948.—Remarques sur trois diabases en coussins de l'Oberhalbstein. *Schweiz. Min. Petr. Mitt.*, 28: 263-273.

————, 1949a.—Variolites et spilites. Comparison entre quelques pillow lavas britanniques et alpines. *Archives des Sciences*, 2, f. 2: 223-236.

————, 1949b.—Sur les pillow lavas dalrađiennes de la péninsule de Tayvallich (Argyllshire). *Schweiz. Min. Petr. Mitt.*, 29: 524-536.

————, 1954.—Le rôle des coulées volcaniques sous-marines dans les chaînes de montagne. *Int. Geol. Congr. C.R., 19th Sess., Algiers*, 1952, fasc. 17: 53-59.

WALKER, G. P. L., 1960.—An occurrence of mugearite in Antrim. *Geol. Mag.*, 97: 62-64.

WATERS, A. C., 1955.—Volcanic rocks and the tectonic cycle. *Geol. Soc. America, Special Paper*, 62: 703-722.

WELLS, A. K., 1923.—The nomenclature of the spilitic suite. Part II. The problem of the spilites. *Geol. Mag.*, 60: 62-74.

————, 1925.—The geology of the Rhobell Fawr district (Merioneth). *Quart. Jour. Geol. Soc. London*, 81: 463-533.

WHITE, D. E., 1957.—Magmatic, connate, and metamorphic waters. *Bull. Geol. Soc. America*, 68: 1659-1682.

WHITEHURST, J., 1786.—*An inquiry into the original state and formation of the Earth: deduced from facts and the laws of Nature.* 2nd edit. London.

WILLIAMS, H., 1932.—Geology of the Lassen Volcanic National Park, California. *Univ. of Calif. Publ., Bull. Dept. Geol. Sci.*, 21, no. 8: 195-385.

WILSHIRE, H. G., 1959.—Deuteric alteration of volcanic rocks. *Jour. Proc. Roy. Soc. N.S.W.*, 93: 105-120.

WILSON, M. E., 1913.—Kewagama Lake map-area, Quebec. *Canada, Geol. Surv., Mem. 39*, no. 35 Geol. Series, 134 pp.

————, 1938.—The Keewatin lavas of the Noranda district, Quebec. *Univ. Toronto Studies, Geol. Series*, no. 41: 75-82.

————, 1960.—Origin of pillow structure in Early Precambrian lavas of western Quebec. *Jour. Geol.*, 68: 97-102.

WOOD, B. L., 1956.—The geology of the Gore Subdivision. *N.Z. Geol. Surv., Bull.*, n.s. 53, 128 pp.
YODER, H. S., JR., and TILLEY, C. E., 1956.—Natural tholeiite basalt-water system. *Carnegie Inst. Washington, Ann. Rept. Director Geophys. Lab.*, 1955-1956, pp. 169-171.
ZAVARITSKY, V. A., 1943a.—Clastic-volcanic rocks in the Bljava pyrite deposits, south Urals. *Acad. Sci. URSS, Bull., Ser. Geol.*, no. 1: 47-58.
————, 1943b.—Some data on the geology of the Uchalinsky pyrite deposit. *Bull. Acad. Sci. URSS, Ser. Geol.*, 1943, no. 1: 59-70.
————, 1945.—The greenstone rocks from the region of the Uchala pyrite deposit in the south Urals. *Bull. Acad. Sci. URSS, Ser. Geol.*, no. 2: 37-53.
————, 1946.—Spilito-keratofirovaya formatsiya okrestnostei mestorozhdeniya Blyavy na Urale. *Akad. Nauk SSSR, Inst. Geol. Nauk*, Tr. v. 71, Petrog. Ser. no. 24, 83 pp. (Not seen.)
ZIRKEL, F., 1870.—*Untersuchungen über die mikroskopische Zusammensetzung und Struktur der Basaltgesteine.* Bonn.
————, 1894.—*Lehrbuch der Petrographie.* Vol. 2. Leipzig.